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Understanding Crude Oil Spot and Futures Prices Dynamics During Major Crises

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Zavadska, M. (2018) *Understanding Crude Oil Spot and Futures Prices Dynamics during Major Crises*. Doctoral thesis, DIT, 2018. doi.org/10.21427/vkjq-5855

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Understanding Crude Oil Spot and Futures Prices Dynamics during Major Crises

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Thesis Submitted for the degree of Doctor of Philosophy



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July 2018

Understanding Crude Oil Spot and Futures Prices Dynamics during Major Crises

2018



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Abstract

This thesis examines crude oil, the dominant energy resource worldwide, its historical behaviour and the resulting implications for world economies. It analyses the role of spot and futures oil prices and their dynamics during periods of market uncertainty. The focus of attention is the understanding of the lead-lag relationship of crude oil spot and futures prices during major crises periods (the first Gulf War in 1990/91, the Asian financial crisis in 1997/98, the US terrorist attack in 2001 and the global financial crisis in 2008/9), and its implications for investors and policy-makers. The mix of applied econometric models gives strength to this study by offering a rich research framework that helps in the analysis and examination of core research outcomes. The study uses daily data to capture fluctuations in the oil markets, more specifically daily closing spot prices and continuous futures prices from 1982 until 2016.

The selected research approach identifies oil prices dynamics and their variations in behaviour during periods of magnified distress such as economic and financial crises. The diversity of approaches is important as they offer an in-depth perspective on oil prices behaviour and how major economic and financial events have impacted on prices behaviour. Different sub samples and time periods are considered for this study, and they are identified by the implementation of structural break tests and moving window approaches. Long run and short run interlinkages are examined by using the Johansen, Engle-Granger and Vector Error Correction models that gave us sufficient evidence to test both spot and futures prices and how their behaviour differs at different points in time. GARCH and OLS models are applied to support the volatility analysis and the variance ratio tests together with bootstrapping and simulation methods that are the basis of the efficiency part of the study.

The results show evidence of a bidirectional long term relationship between crude oil spot and futures prices for all sub periods. However, the short term relationship provides different outcomes, where for stable and post-crises periods futures prices seem to have a leading role, while spot prices appear to be leading during crises periods. This research outcome can be considered as a major contribution of this study, as it offers very interesting information and insights to investors and oil dependent industries, as they can follow either spot or futures prices depending on the length of their business strategy and oil price levels during different financial and economic episodes. The volatility analysis reveals that crises triggers play an important role in volatility examination, where in cases of economic and financial distress the volatility persistence lasts longer with lower volatility spikes, which is in contrast with fundamental triggers of supply and demand, where the increased volatility does not last as long, but shows evidence of clearly higher volatility spikes. The conducted analysis looking at market efficiency suggests that crude oil markets are efficient in the short run, but not in the long run, which can be due to the high number of structural breaks identified in the analysed sample and which are caused by the registered high oil market volatilities over time. These findings offer interesting insights regarding the lead-lag relationship between spot and futures prices of the main crude oil benchmarks during different crises, which can be used by academics, oil market participants, policy-makers and speculators. The main contribution of this thesis results is the understanding of the relationship and dynamics for business and strategic investment decisions through risk management and long term planning, especially for economies that are highly dependent on oil as their main energy source.

Declaration

I, Miroslava Zavadska, certify that this thesis which I now submit for examination for the award of the Doctor of Philosophy in Economics is entirely my own original work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for graduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for any other award in any other third level institution.

The work reported on in this thesis conforms to the principles and requirements of the DIT's guidelines for ethics in research.

DIT has permission to keep, lend or copy this thesis in whole or in part, on condition that any such use of the material of the thesis be duly acknowledged.

Miroslava Zavadska

Date

Conferences and Publications

The research papers that are part of this thesis were accepted and presented at national and international conferences listed below:

Conferences

1. Zavadska, M., Morales, L., and Coughlan, J. “The Importance of Integrating Quantitative Research Methods to Understand Commodity Business Finance” Paper presented at the 34th IISES International Academic Conference, 13-16 September (2017), Florence, Italy.
2. Zavadska, M., Morales, L., and Coughlan, J. “The Efficiency Analysis of Crude Oil Spot and Futures Prices: A Moving Window Approach” Paper presented at the 34th IISES International Academic Conference, 13-16 September (2017), Florence, Italy.
3. Zavadska, M., Morales, L., and Coughlan, J. “Oil Price Movements in Times of Crisis: The Gulf War & the Global Financial Crisis” Paper presented at the 16th European Conference on Research Methodology for Business and Management Studies, 22-23 June (2017), Dublin, Ireland.
4. Zavadska, M., Morales, L., and Coughlan, J. “The Efficiency Analysis of Crude Oil Spot and Futures Prices using Moving Window Approach” Paper presented at the 4th Young Finance Scholars’ Conference, 12-13 June (2017), Brighton, UK.

5. Zavadska, M., Morales, L., and Coughlan, J. “Efficiency of Crude Oil Spot and Futures Prices” Paper presented at the 15th INFINITI Conference on International Finance, 12th-13th June (2017), Valencia, Spain.
6. Zavadska, M., Morales, L., and Coughlan, J. “The Efficiency Analysis of Crude Oil Spot and Futures Prices using Moving Window Approach” Paper presented at the 5th International Symposium on Environment Energy & Finance Issues Annual Conference, 22-23 May (2017), Dublin.
7. Zavadska, M., Morales, L., and Coughlan, J. “Efficiency of Crude Oil Spot and Futures Prices: A Moving Window Approach” Paper presented at the 30th Irish Accounting and Finance Association Annual Conference, 17-19 May (2017), Athlone, Ireland.
8. Zavadska, M., Morales, L., and Coughlan, J. “Oil Prices Volatility Crises Periods” Paper presented at the ECOMFIN 2016: Energy and Commodity Finance Conference, ESSEC Business School, 23-24 June (2016), Paris, France.
9. Zavadska, M., Morales, L., and Coughlan, J. “Oil Prices Performance during Times of Crises” Paper presented at the 14th INFINITI Conference on International Finance held at Trinity College, Dublin , 13-14 June (2016), Dublin, Ireland.
10. Zavadska, M., Morales, L., and Coughlan, J. “Oil Prices Volatility during Turbulent Times” Paper presented at the 29th Irish Accounting & Finance Association Annual

Conference, 19-20 May (2016). School of Business, Waterford Institute of Technology, Waterford, Ireland.

11. Zavadska, M., Morales, L., and Coughlan, J. “Brent Crude Oil Spot and Futures Prices Dynamics during Times of Crises” Paper presented at 13th INFINITI Conference on International Finance hold at the University of Ljubljana, 8-9 June (2015), Ljubljana, Slovenia.

12. Zavadska, M., Morales, L., and Coughlan, J. “Oil Price Movements in Times of Crisis: The Gulf War & the Global Financial Crisis” Paper presented at the 28th Irish Accounting and Finance Association Annual Conference, 14-15 May (2015), Dublin, Ireland.

Publications

1. Zavadska, M., Morales, L., & Coughlan, J. (2018). The Importance of Integrating Quantitative Research Methods to Understand Commodity Business Finance. *International Journal of Business and Management*, VI, 54-77. Published. [Based on the Research Methodology Chapter]

Acknowledgements

The biggest thank you goes to my supervisors Dr. Lucía Morales and Prof. Joseph Coughlan. I would like to express my sincerest gratitude to them. I especially want to thank Lucía for her never ending support, advice, patience and most helpful comments, which assisted with the completion of this thesis. Also, I thank Joe for his extensive experience and wisdom. I highly appreciate all your help and encouragement throughout the thesis.

I am also very grateful to Paul O'Reilly, the former Head of Research, Learning and Development in DIT College of Business, for his assistance and help with the PhD grant proposal for a Fiosraigh Scholarship, which helped in obtaining the four year PhD research grant.

I devote my wholehearted thank you to my husband for his love and understanding from the beginning of my doctoral thesis. Your support and love during difficult times helped me to progress and finish my research.

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² Tables are part of each research paper (Paper 1 in Chapter 4, Paper 2 in Chapter 5 and Paper 3 in Chapter 6)

Chapter 1

Introduction

1. Introduction

Understanding crude oil prices dynamics is fundamental for oil dependent economies, as they are tightly connected with the economic performance of oil dependent industries, where crude oil is the main cost factor for businesses. High levels of volatility are considered typical for crude oil markets, as uncertainty and unexpected oil price jumps dynamically affect economies. Oil price jumps and uncertainty significantly disturb markets, and as such, many scholars and analysts have looked into this problematic issue (Bekiros and Diks, 2008; Charles and Darné, 2009; Salisu and Fasanya, 2013; Hamilton, 2014; Robe and Wallen, 2016). The existing literature mainly discusses single events or issues in the oil market, but there is a need to analyse in detail the major shocks and oil prices movements which shake the oil market the most, through gathering econometric outcomes for such periods and the historical behaviour of crude oil price dynamics over a long period of time. Therefore, the lead-lag relationship and the identification of the dominant oil price (spot or future), and the behaviour of crude oil spot and futures prices during stable and crises periods is important not only for academics, but also for investors, oil market participants and policy makers.

This chapter starts with an oil market background explaining elementary facts about crude oil markets, its uses, types of extraction, initial insights on the lead-lag relationship and existing literature on oil price dynamics during times of crises. This is followed by the outlining of the main research aims and objectives, and research questions. The thesis is organised into three papers and each will be briefly described. Then there is the presentation of and insight on the research

motivation which is based on the need and importance of this type of study considering crises periods. The value added of this thesis is due to the lack of analysis of the implications of major shock events in the dynamics between oil spot and future prices and is considered as the centre piece of this study. Lastly, the summary and conclusions of this chapter are presented.

1.1 Crude Oil Background

Crude oil is the main energy resource worldwide and currently there is no sustainable alternative to it, as there is no other resource that has similar properties available at a similar cost. Oil is a fossil fuel that exists in liquid form in pools under the ground or near the surface in sands. It will remain as a major energy resource for the years to come as the need for crude oil is growing continuously. Even with renewable energies and technological advances, crude oil remains the dominant energy source in many key industries. It accounts for 35-40 percent of the global energy demand (EIA, 2016). The growing demand for oil is associated with activities that involve transport, the generation of heating, electricity and petrochemical production. In 2015 the transport sector accounted for nearly 65 percent of the crude oil demand to fuel vehicles, planes and ships (EIA, 2016). Global oil consumption grew on average 1.6 million barrels per day in 2016, which represents a 1.6 percent increase, its 10-year average (BP, 2017). Remarkably, the world's most populous countries - China and India - exhibited the largest increase in oil consumption in 2016. This suggests that the largest growth in oil consumption continues to be centralised in the Asian continent.

Technological advances and renewable energies also play an important role at this time, and impose constraints on developed countries through environmental pressure on oil extraction. A changing pattern in developing economies shows increasing demand for oil, which affects trade activities, as far more oil is shipped to Asia. Oil transportation, storage and refinery also need to be considered

with changing technological trends and oil flows around the world. On the other hand, increases in oil production have been quite slow since 2013. It rose by only 0.4 million barrels per day on average in 2016. In 2016, production in the Middle East rose by 1.7 million barrels per day, driven by Iran, Iraq and Saudi Arabia. This contrasts with production declines experienced in the US, China and Nigeria, where production dropped by 1.3 million barrels per day in 2016 (BP, 2017).

The fear about crude oil scarcity is easing with new production technologies, where oil is extracted from oil sands in Canada and from shale in the US (Reuters, 2018). New technologies and exploration improvements are being used to transition to more environmental friendly energies that are part of key strategies for developed countries to support growth and energy sustainability of their economies (Corma et al., 2018). The high-tech equipment and innovative solutions save considerable costs for drilling companies making crude oil cheaper to consumers. For example, costs of oil drilling can be low as \$20 per barrel compared to costs of coal of above \$30 per ton plus high transportation costs (Oil Price, 2018), which gives crude oil a price advantage over other energies and its dominant position. The common oil extraction types use conventional and unconventional technology. The conventional way includes drilling the ground, where oil is liquid at atmospheric temperature and does not need additional stimulation to flow. Unconventional oil extraction involves new techniques which accesses those oil reservoirs that cannot be reached by established drilling methods. These are used for shale oil and oil sands drilling.

Oil extraction brings some negative effects to the environment, which is putting pressure on the transition process to more environmental friendly resources. For example, oil spills on land and offshore are a big issue, which have devastating long term effects for nature and that significantly affect animals and humans by causing health problems as a result of direct inhalation and ingestion of toxic oil through contamination, or indirect effects that are associated with potential cancer

development. Other environmental issues are linked to landscape changes affecting wildlife, noise and light pollution, high levels of methane emissions and potential climate change. All these factors play a role in encouraging the finding new environmentally friendly resources; however, this can take a substantial amount of time and resources, and as such, the low cost and properties (quality characteristics such as density, gravity and sulphur content) of crude oil maintains its dominant role in the energy markets and oil dependent economies as being the main energy source worldwide.

The crude oil market has experienced numerous fluctuations over time and it is considered as one of the most volatile commodity markets. There are various triggers impacting crude oil prices. The main triggers are supply and demand shocks, business cycles, speculative activities, economic, financial and political instabilities (Hamilton, 2014; Robe and Wallen, 2016). For example, the first and the second Gulf war, caused by political unrest, led to oil supply disruptions. On the other hand, during the Asian financial crisis and the global financial crisis, oil price fluctuations were mainly caused by inefficiencies in financial markets further transmitted to the oil markets due to uncertainty and lower demand levels for the resource. Consequently, it is essential for oil market participants to identify the main reasons for oil price jumps and the degree of oil price changes depend on the specific trigger. This study has implications for crude oil futures as the most traded futures contracts in the world; thus, they are included in this study together with oil spot prices as both of them are affected by shock events. In this way the lead-lag relationship can offer insights of the dominant crude oil price indicator during episodes of major crises. As Bekiros and Diks (2008) pointed out both spot and futures prices reflect the same aggregate value of the underlying asset.

1.2 Research Objectives and Main Research Questions

The understanding of oil price dynamics and the relationship between crude oil spot and futures prices is of great importance as both markets are used as indicators of oil prices. As oil remains the main energy source it plays a key role in the world economy, and therefore the analysis of crude oil prices is vital for many economic and financial players. Some of the main studies cited in this thesis looking at the dynamics and relationship of crude oil prices undertaken over the past decades are listed in Table 1.1. These papers are selected based on the key analytical elements of this thesis and are chosen over other papers based on their high level of citation within the sub-field of their study. The existing literature mainly considers questions regarding investments, portfolio management and policies needed for market regulation. The analyses look at specific time periods and modelling techniques to answer particular points of interest, where the time periods are usually selected for specific events. For example, Table 1.1 includes the work of Bekiros and Diks (2008), Wang and Wu (2013) and Ding et al. (2014) who analyse the long and short term relationship of crude oil prices for particular time periods but do not consider crises periods as the main point of interest. The volatility research and forecasting studies conducted by Sadorsky (2006), Salisu and Fasanya (2013), Charles and Darné (2014) and Wang et al. (2016) also offer analysis for certain time periods, but there is also a need to look at combinations of crises and major shocks to understand oil price behaviour during such occasions to be able to predict and adjust investment and planning strategies. Similarly, efficiency analysis conducted by researchers such as Serletis and Andreadis (2004), Charles and Darné (2009) and Gu and Zhang (2016) provide results for the efficiency of the main oil benchmarks, usually WTI or Brent, using different time periods and frequencies in their examination. Efficiency analysis is very important as it has many implications for investors and policy makers. If oil markets are found to be not efficient, it means that investors cannot rely on the true value and prices of oil and would expect abnormal returns for their investments. On the other hand, if oil prices

are efficient and oil prices reflect all available information, it brings trust in the market and more investors are willing to include crude oil in their investment portfolios.

Table 1.1: Selection of Reviewed Literature

Theme	Article	Issue Covered	Research Gaps
Relationship and dynamics	Bekiros and Diks (2008)	Long and short term relationship between spot and futures oil prices of West Texas Intermediate (WTI)	Relationship between spot and futures oil prices during multiple crises is missing in the literature
	Wang and Wu (2013)	Long term relationship between WTI spot and futures prices	
	Mehrrara and Hamldar (2014)	Long and short term relationship between Brent spot and futures prices	
	Ding et al. (2014)	Short term relationship of WTI prices	
	Mitra (2018)	Short term and long term relationship between oil and stock prices	
Structural breaks	Lee et al. (2010)	Evidence of structural breaks in crude oil markets	Structural break analyses are in this thesis used to identify pre-crisis, crisis, post-crisis periods for multiple shock events in the oil market
	Salisu and Fasanya (2013)	Structural breaks in oil time series	
	Charles and Darné (2014)	Numerous structural breaks affecting oil series	
	Mensi et al. (2014)	Importance of structural breaks in oil markets	
Volatility analysis	Sadorsky (2006)	Oil price fluctuations	Volatility analysis for main shock events and relatively stable periods before and after crises is missing
	Wang and Wu (2012)	GARCH modelling in energy markets volatility	
	Salisu and Fasanya (2013)	Volatility analysis with structural breaks	
	Charles and Darné (2014)	Volatility persistence in crude oil markets	
	Wang et al. (2016)	Forecasting oil market volatility	
	Antonakakis et al. (2018)	Oil volatility	
Efficiency analysis	Serletis and Andreadis (2004)	WTI price efficiency	Efficiency analysis for three main crude oil benchmarks (Brent, WTI and Dubai crude) is needed to understand price efficiency during turbulent times
	Lim et al. (2008)	Impact of OPEC on oil efficiency	
	Charles and Darné (2009)	Crude oil markets efficiency	
	Khediri and Charfeddine (2015)	WTI market efficiency	
	Gu and Zhang (2016)	WTI efficiency	

Source: Author (2018)

The research gaps, identified by reviewing early studies and more up to date literature, are discussed in Section 2 (Literature Review). The conducted literature review helps to identify the time frame of this thesis, where the historical development concentrates on over 30 years of data to detect the major crises affecting oil prices, which is an aspect that existing studies have not considered, and that this thesis addresses. Therefore, the objective of this thesis is to look at historical behaviour and dynamics of crude oil spot and futures prices, as both prices need to be analysed for completeness of this research. The time period from 1982 to 2016 provides a wide overview of oil price changes over time, where frequent jumps and shocks in the oil market shook not only oil dependent industries, but also some of the world's major economies. Therefore, the implications of times of distress and significant volatility regarding interlinkages between spot and futures prices and overall performance of the oil markets are the main concern for the analysis as they go hand in hand with market and financial uncertainty. This validates the research objectives of the thesis, which comprises three main research questions looking for answers on oil prices behaviour during crises periods. This kind of approach is missing in the existing literature and by addressing them this thesis makes a significant contribution to remedying that deficiency. Thus, to understand oil price dynamics and changes during unstable times, the main research questions are identified below.

The three research questions and associated hypotheses are as follows:

1. Firstly, the examination of the long term and short term relationship between spot and futures prices is conducted. This is done to test the importance of both prices during pre-crisis, crisis and post-crisis periods that would offer initial views on the oil prices behaviour and gives rise to our first research question.

Q_1 : Is there a long and/or short run (cointegration and causality) relationship between crude oil spot and futures prices?

The hypotheses under consideration in this case are as follows:

H_{10} : *There is a long run relationship between crude oil spot and futures prices.*

H_{1A} : *There is no long run relationship between crude oil spot and futures prices.*

H_{20} : *There is a short run relationship between crude oil spot and futures prices.*

H_{2A} : *There is no short run relationship between crude oil spot and futures prices.*

2. Secondly, volatility analysis is performed to test the persistence and degree of volatility jumps for numerous crises periods caused by different triggers. Supply and demand shocks together with financial crises influencing the economy are included to look for the effects on oil prices, which gives rise to the second research question under consideration.

Q_2 : Is the volatility of crude oil spot and/or futures prices higher during periods of crises?

The hypotheses are as follows:

H_{30} : *Crude oil spot and/or futures prices are more volatile during periods of crises.*

H_{3A} : *Crude oil spot and/or futures prices are not more volatile during periods of crises.*

3. Thirdly, the analysis looks at oil market efficiency over long, medium and short term periods. The efficiency framework investigates Fama's (1965, 1970) random walk hypothesis and its goal is to test if prices are predictable, which will open arbitrage opportunities to investors and speculators, and therefore the third research question is as follows.

Q_3 : Are crude oil spot and/or futures prices efficient in the long, medium and short run?

The hypotheses are as follows:

H₄₀ : Crude oil spot and/or futures prices are efficient in the long run.

H_{4A} : Crude oil spot and/or futures prices are not efficient in the long run.

H₅₀ : Crude oil spot and/or futures prices are efficient in the medium run.

H_{5A} : Crude oil spot and/or futures prices are not efficient in the medium run.

H₆₀ : Crude oil spot and/or futures prices are efficient in the short run.

H_{6A} : Crude oil spot and/or futures prices are not efficient in the short run.

The above research hypotheses guide the analysis of crude oil markets during numerous crises periods. This adds value to the existing literature when specifically looking at patterns during different shock events. The study is supported by the examination of a long time period starting in 1982 (with the availability of the data to cover the pre-crisis period of the first Gulf War in 1990) and ending in 2016 (to capture the period after the global financial crisis), which provides sufficient number of observations for multiple econometric models. The inclusion of three main crude oil benchmarks (Brent, WTI and Dubai crude) brings this research even further and adds value to past and current literature in this field. As a result, this thesis offers a complete and comprehensive view on oil markets behaviour during various shocks events. The study is presented through three key research papers, presented in Figure 1.1, that allow the development of an in-depth study considering spot and futures prices linkages. This helps to get a better understanding on their connections during times of remarkable instability and facilitates the progression of the study by moving on from the analysis of prices interlinkages, volatility considerations and understanding of market efficiencies that are remarkable aspects in the field but which need to be considered together to get a better understanding of oil market behaviour and overall dynamics.

The significance of three research papers adds value by exploring three different but interconnected themes shown in Table 1.2, which were chosen after the analysis of the reviewed literature that was used as a guide for drawing up the outlined research questions.

Table 1.2: Research Papers Themes

Paper	Title	Explanation	Time Period	Crises	Oil Benchmarks
1	Brent Crude Oil Spot and Futures Dynamics during Times of Crises	Long term and short term relationship analysing the lead-lag relationship between spot and futures oil prices	1988 to 2013	The first Gulf War in 1990/91; the global financial crisis in 2008/9	Brent
2	Brent Crude Oil Prices Volatility during Major Crises	Volatility analysis examining volatility spikes and persistence during crises	1988 to 2013	The first Gulf War in 1990/91; the Asian Crisis in 1997/98; the US terrorist attack in 2001; the global financial crisis in 2008/9	Brent
3	Efficiency Analysis of Crude Oil Spot and Futures Prices	Efficiency analysis exploring efficiency of oil prices	1986 to 2016	The first Gulf War in 1990/91; the Asian crisis in 1997/98; the US terrorist attack in 2001; the global financial crisis in 2008/9	Brent, WTI, Dubai

Source: The Author (2018)

This thesis analyses the main crude oil benchmarks, where Brent represents the European market, West Texas Intermediate (WTI) represents the US market and Dubai crude represents the Middle East market. The main interest is to find any repeating patterns in the past behaviour of the series to be able to infer and predict future performance and the degree of oil market change connected to specific triggers. This will give a great advantage to all interested parties to speed up their business and investment decisions together with future planning, which will minimise the uncertainty and risk exposure by knowing the leading price and connection between oil prices, and the duration and impact intensity of shocks on oil prices. This could also help a country's overall GDP through determining government policies to reduce the impact of shocks.

1.3 Research Motivation

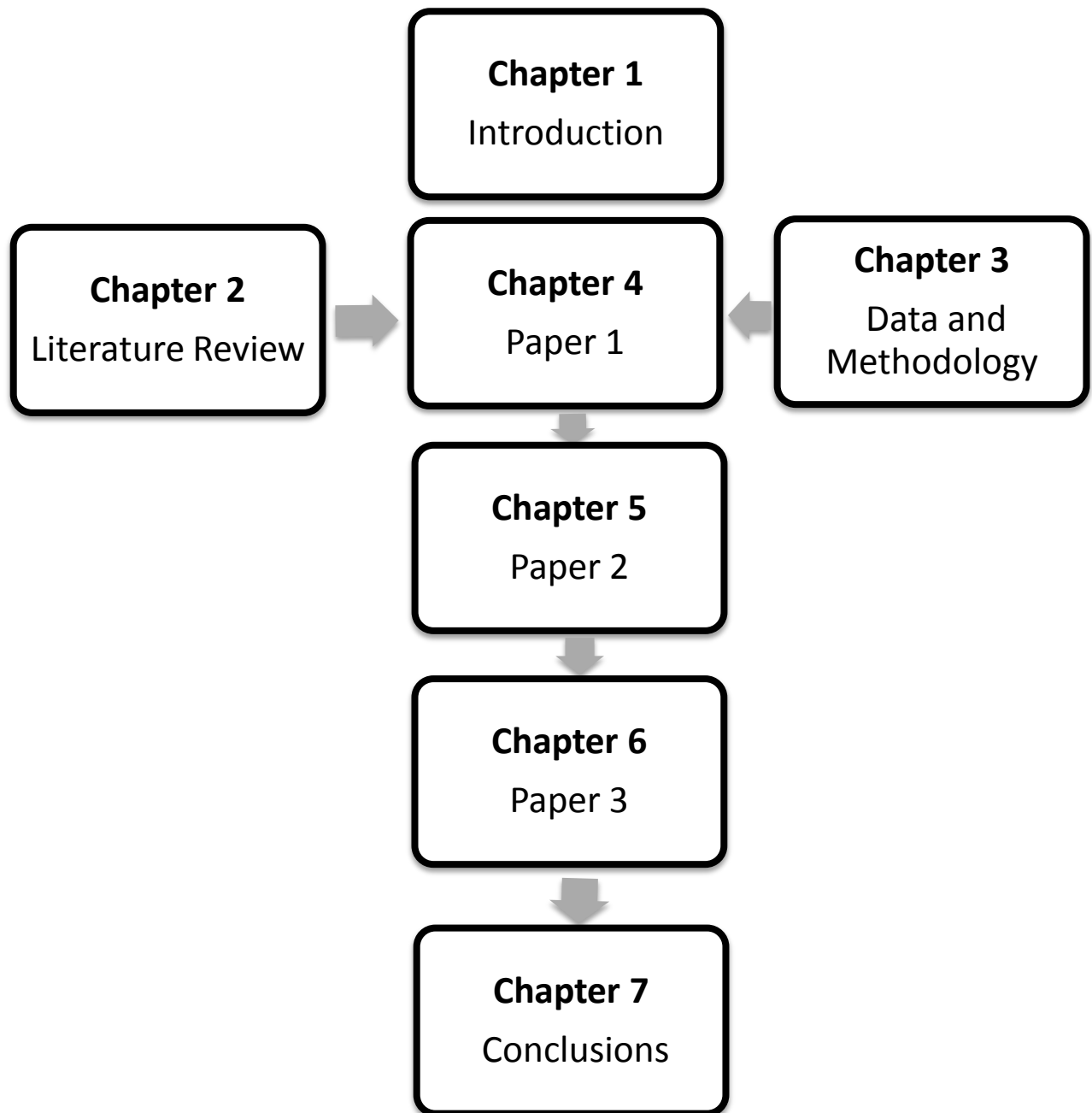
Existing research conducted by researchers such as Sadorsky (2006), Charles and Darné (2009 and 2014), Salisu and Fasanya (2013), Mensi et al. (2014), Gu and Zhang (2016) and Wang et al. (2016) mainly examine a single crude oil benchmark or only look at spot or futures prices. Their approaches need to be extended to recognise the impact being made by different geographic benchmarks, including spot and futures prices, during turbulent periods. Such analysis will help academics and all interested parties in the oil market with decision making and planning strategies. It will provide useful information regarding long term planning, where such analysis could speed up buy/sell/hedge/hold decisions and lower business costs considerably. The scope of this research could be also used by governments and policy makers when implementing future procedures and guidelines for oil dependent industries. The existing literature shows clearly that research of energy markets brings significant insight to oil market participants. However, there is a need to extend market knowledge by focusing on the dynamics during major crises periods as they have a great impact on oil price behaviour; they affect prices relationships and as a result they will impact on the

development of policies, decision making processes and have overall implications for oil dependent economies.

1.4 Thesis Structure

The structure of the thesis starts with an introduction, a literature overview of crude oil spot and futures markets and their relationship. It is followed by a discussion on the role of OPEC and speculation in the market. It continues with the presentation of a brief background of key shock periods influencing crude oil markets. Subsequently, the methodology selection and techniques used are presented. Afterwards, papers one; two and three are included as separate chapters. In view of this, the next chapter (Chapter 2) discusses the overview of the existing literature, which is followed by the methodology chapter (Chapter 3) dealing with data and econometric models applied in this thesis. The following three chapters (Chapter 4, Chapter 5 and Chapter 6) include the developed research articles, and the main findings, implications and value of the conducted research points that are summarised in the last chapter (Chapter 7) of this thesis as shown in Figure 1.1.

Figure 1.1: Thesis Structure



Source: The author (2018)

Each research paper offers a focused answer to the outlined research questions discussing long and short term relationships, volatility analysis and efficiency testing. The three interconnected research papers provide the opportunity to identify the most suitable methodologies for each area of study.

This gives strength to crude oil examination during crises periods by helping to answer our main research questions on oil prices behaviour during shock events. The last chapter of the thesis discusses the contributions of the thesis and offers conclusions and suggestions for future research.

Chapter 2

Literature Review

2.1 Introduction

The literature review's main purpose is to give an overview of the literature, as more detailed discussions are provided in the individual papers, in Chapters 4 to 6. This chapter starts with an overview of the dynamics and behaviour of crude oil spot and futures markets and their price evolvments. The main themes of the existing research discuss the lead-lag relationship between spot and futures prices to understand the dynamics between the two markets and to settle the foundations of the discussions that seek to get a better understanding of the connections that exist between prices and how they might be affected by episodes of significant market uncertainty. The discussion follows with the literature examining the Organisation of Petroleum Exporting Countries (OPEC) and its role in crude oil markets with particular attention to the role of speculation, suggesting that it may be a player in setting oil prices and impacting their dynamics and behaviour. Subsequently, the literature focusing on structural changes in oil markets is presented. Finally, the literature looking at volatility and efficiency issues is discussed. Special attention is paid to crises periods and their impact on crude oil fluctuations. The chapter concludes with a summary of the main research studies in the field and itemises their contribution to the existing literature and identifies the gaps in research that this thesis seeks to address.

2.2 Oil as a Financial Asset

Crude oil is a commodity. Since oil started being traded in the derivatives markets through futures contracts, its use has expanded to it becoming a financial asset. WTI futures contracts in 1983, Brent in 1988 and Dubai futures contracts in 1991 started being traded in derivatives markets with CBOT and NYMEX (CME Group, 2017). The available data for forward contracts goes back to the 1970s. As this thesis analyses both spot and futures prices and the initial crisis in the first Gulf war in 1990, the time span of this research was decided due to the availability of data from 1982 up to 2016 to facilitate the historical study of futures and spot prices interlinkages. Oil demand is not the only oil price setter. Speculation has an impact on oil prices also. Investors who buy and sell oil futures as a financial asset hold about 50 percent of oil futures. This percentage is growing steadily (Masters, 2008). Weiner (2002) noted that the increasing presence of non-commercial traders does not necessarily increase oil price volatility if their trading decisions are based on rational expectations and efficient market hypotheses. However, oil price volatility is greater if non-commercial traders base their buy and sell decisions on technical analysis, contagion or extrapolation (Weiner, 2002). The traders' investment positions are part of a cointegrating relationship between spot and futures prices (Kolodziej and Kaufmann, 2013).

Kolodziej et al. (2014) pointed out that increased oil price changes could be also due to capital flows among markets. Large capital flows between equity and commodity markets could change commodity prices beyond trends given by their market fundamental levels. This arises because commodities are used as a hedge against investments in equity markets, and crude oil in particular fulfils this role. Changes in economic conditions or structural changes can also give rise to inverse correlation (Park and Ratti, 2008). Tang and Xiong (2012) suggest that the change from negative to

positive correlation of oil prices returns and stock returns could be caused by financialisation³ of the oil market, and Büyüksahin and Robe (2014) noted that it could be due to the increasing participation of hedge funds. Kolodziej et al. (2014) also studied the relationship between equity and oil markets and found that the returns on WTI and S&P 500 were negative from 2003 to 2008, but from 2009 the correlation between the returns flipped to positive. They suggest that this was caused by a large reduction in interest rates during the fourth quarter of 2008. This reduction in interest rates is associated with lower convenience yields⁴ and a change from backwardation⁵ to contango⁶ in the futures markets. These changes mean that crude oil is less attractive to hold as a commodity and more attractive to hold as a financial asset, and therefore there is a need to study both spot and futures oil prices to understand the behaviour and dynamics over time.

As noted by Bekiros and Diks (2008) and Ding et al. (2014), futures prices may play a bigger role in setting oil price levels than spot prices and therefore are a better oil price indicator. If this finding is correct and applies for all market conditions, it would be a very powerful discovery. Is it true? Can we rely on that? That is certainly a statement which must be tested. Zhang and Wang (2013) believe that futures prices have a dominant role in crude oil markets over spot prices, but this does not seem to apply continuously over time. Additionally, Kim (2015) suggests that there is a positive impact of speculation on crude oil markets particularly during the recent financialisation period. The financialisation period stands for a period of increasing importance of financial markets and their liberalisation. It is a topic associated with the global financial crisis where the housing bubble and

³ Financialisation is a term used to describe the increased influence of financial markets and financial institutions over economic policy and economic outcomes. It is mainly used for the period from 1980s to 2010 for countries, where the debt-to-equity ratios increased and financial services accounted for higher shares of national income relative to other sectors (Tang and Xiong, 2012).

⁴ Convenience yield is the premium associated with holding an underlying commodity rather than a futures contract of the asset.

⁵ Backwardation is when the futures price of a commodity is below the expected future spot price.

⁶ Contango is a situation where the futures price (or forward price) of a commodity is higher than the expected spot price.

the collapse of Lehman Brothers⁷ played an important role. These authors do not claim that spot prices do not matter in the oil price discovery process, and therefore should not be left out during decision making processes, helping to decide on the importance of testing both spot and futures prices.

Su et al. (2017) also examined the extent of speculation and oil price bubbles in respect of WTI from 1986 to 2016. In their analysis they find six bubbles in the oil market, which includes a fundamentals component and a speculation component. The identified dates of bubbles correspond to particular events in financial markets and politics. They suggest that policy-makers should observe the creation of oil price bubbles and reduce them by implementing certain strategies to stabilise the oil markets. The cause of bubbles for specific events should be monitored to help reduce the impact on the real economy. These are the key issues and facts supporting the importance of this thesis and its objective in examining crude oil price behaviour during crises periods as it could expose similar patterns during shock periods.

It is also known that the oil price level and its changes affect oil dependent countries' GDP levels and therefore constant awareness of supply levels and the political situation is needed. Although spot and futures oil markets include different type of investors, where on one side oil dependent sectors buy the commodity itself, there are also investors entering futures markets to speculate or hedge against price changes. Existing research includes analysis examining either spot or futures prices, or some studies investigating spot and futures prices for a specific oil benchmark (Sadorsky, 1999; Bekiros and Diks, 2008; Mehrera and Hamldar, 2014). Therefore, the relationship between spot and futures prices during crises and stable periods needs to be understood to help with decision making processes during uncertain times.

⁷ Lehman Brothers was an investment and banking company offering global financial services. It was the fourth largest investment bank in the US and deeply involved in mortgages. It was very vulnerable to real estate value downturn, which essentially triggered its bankruptcy in 2008.

2.3 The Role of OPEC and Speculation

The Organisation of the Petroleum Exporting Countries (OPEC) is an intergovernmental organisation created at the Baghdad conference in September 1960 by Iran, Iraq, Kuwait, Saudi Arabia and Venezuela. In 1961 Qatar joined the organisation; Indonesia joined in 1962, but left the organisation in 2009. Other members are: the United Arab Emirates (1967); Algeria (1969); Nigeria (1971); Ecuador (1973); Angola (2007) and Gabon (1975 to 1994). OPEC has its headquarters in Vienna, Austria since September 1965; in previous years its headquarters was in Geneva, Switzerland (OPEC, 2015).

The main objective of the OPEC is to coordinate and unify petroleum policies among its eleven member countries. This is done in order to secure fair and stable oil prices for oil producers; an efficient economic and regular oil supply to consuming nations; and a fair return on capital to those investing in the industry (OPEC, 2015). In other words, since oil revenues are majorly important for the economic development of the OPEC countries, their objective is to bring stability and harmony to the oil market by adjusting their oil output to balance the supply and demand of oil (Noguera and Pecchechnino, 2007). Noguera and Pecchechnino (2007) explained that the OPEC cartel was formed to promote two economic goals. The first one is to keep low oil market volatility from a microeconomic perspective, and the second is to encourage economic development of its members from a macroeconomic perspective. These two goals can create tension within the cartel, because their only tool to achieve these goals is based on output quotas. The cartel choices on the levels of oil production have an impact on the stability of the oil market and long term macroeconomic development (Loderer, 1985).

Griffin (1985) noted that the OPEC cartel was established to take some sovereign control over oil resources and to ensure a world market share in the oil industry. The target of stable oil prices and

economic development of its member states differentiated it from regular cartels whose main goal is to maximise joint profits. Comparing OPEC countries with other developing economies, they are characterised by very high population growth rates and high dependence on oil in terms of personal income and public finances (Noguera and Pecchechino, 2007). High extraction rates and low investment in the oil sector have led to falling oil reserves. Cordesman (2001) claims that many oil producing nations do not have the resources to develop their own oil reserves. Due to a high level of oil dependency, the oil sector must perform well to maintain current and future living standards (Morrison, 2004). To maintain targeted oil prices, OPEC can adjust its oil supply, but it cannot control market demand to get needed revenues for national income and stability. When OPEC was founded in 1960, the oil market was quite stable, and the cartel strategy worked, but with high oil market volatility, the OPEC goals of long term growth and development may not be achievable via the unitary profit-orientated pricing policy (Jalali-Naini and Asali, 2004).

Bremond et al. (2012) investigated the existence of a cartel within the OPEC organisation by testing whether production decisions are coordinated and if they influence oil prices. They found an of OPEC's influence and changes in the oil pricing system. The pricing system has transformed over the past 50 years from an administered to a market related price system in the 1980s due to the introduction of the derivatives markets (Bremond, 2012). At the beginning of the 20th century, the posted price period with different pricing systems in the physical market (Single Basis System) was implemented by the International Oil Companies (IOC). According to Fattouh (2006) the aim of this pricing system was to lower the tax paid by the IOC to the host countries, which led to a very low and stable official price independent of market conditions. At the end of 1950s, Russian entry into the market triggered a major change with a huge production surplus. The 'Seven Sister's'⁸ reaction to

⁸ The Seven Sisters companies dominated the oil industry and controlled about 85% of the world's oil reserves from mid-1940s to the 1970s. The group comprised of BP, SoCal, Chevron, Gulf Oil, Royal Dutch Shell, Esso and ExxonMobil (all in today's names).

this was a 10 percent cut in the posted prices to keep their market share (Bremond, 2012). This could be considered as a trigger for OPEC's creation in the 1960s.

It took 13 years for the OPEC organisation to get the power to be able to influence oil prices. The oil market and its pricing systems has experienced many changes since 1973⁹. The behaviour and theories of OPEC being a cartel were previously investigated. For example, Dahl and Yucel (1989) tested these theories and found that the OPEC is not a cartel as some countries within the organisation behave in a non-cooperative way or with a target revenue goal. However, if we consider various sub-periods, Loderer (1985) pointed out that OPEC acted as a cartel during the beginning of 1980s in comparison to the 1974 to 1980 period, where this theory is rejected. Gullen (1996) also found that OPEC production Granger causes oil prices from 1982 to 1983, meaning that OPEC's decisions affect oil prices.

Some studies consider OPEC as being a divided cartel. Hnyilicza and Pindyck (1976) split the OPEC countries into two groups. One group is called 'saver'¹⁰ and a second group is called 'spender'¹¹. The spender countries include members with an immediate need for cash and a rate of discount lower than the saver members. Aperjis (1982) pointed out that conflict regarding production decisions can exist between OPEC members. Alhajji and Huettner (2000) also noted that OPEC does not act as a cartel. Even though OPEC is used as an example of a cartel, there is insufficient evidence from available statistical tests or theories that support this claim. As a commodity, the supply-demand model could be applied to the oil market (Bacon, 1991), but this approach is difficult to use due to oil's specific characteristics. A demand curve, which relates quantities to prices, can accurately

⁹ The 1973 Oil Crisis was triggered by an embargo by Arab oil producers boycotting America and the West in response to their support to Israel in the Yom Kippur war against Egypt. This led the price of crude oil to rise and made all transport more expensive.

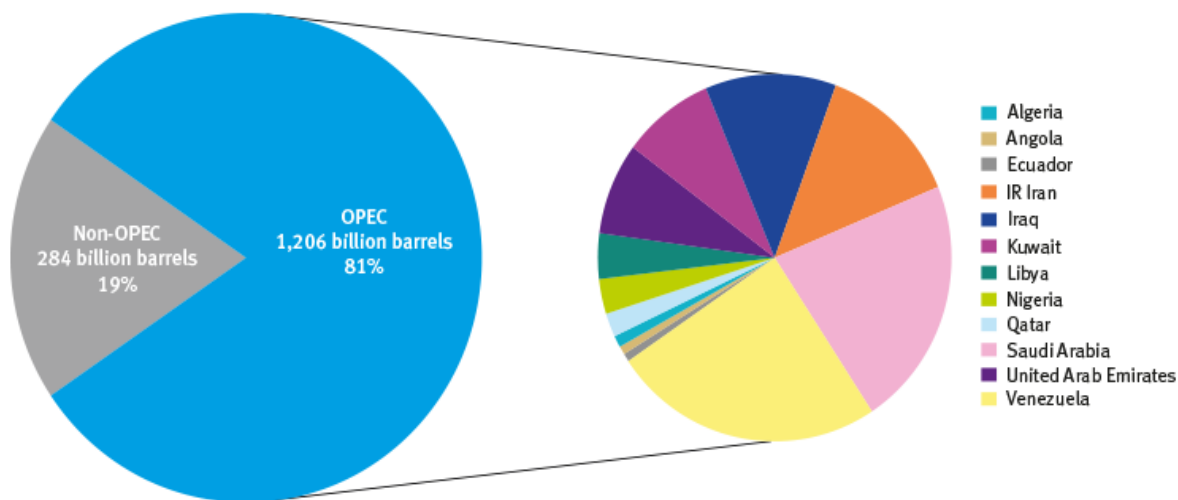
¹⁰ Saver countries include Saudi Arabia, Libya, Iraq, Abu Dhabi, Bahrain, Kuwait and Qatar.

¹¹ Spender countries include Iran, Venezuela, Indonesia, Algeria, Nigeria and Ecuador.

represent oil demand, but modelling oil supply is more difficult. The reason for this is that oil is also supplied by independent oil producers (non-OPEC countries) that act as price takers, and OPEC countries determine levels of production and fix capacity (see Figure 2.1). The aspects of OPEC production and changing market conditions affect real oil prices (Kaufmann et al., 2004).

Figure 2.1: OPEC and Non-OPEC Reserves

OPEC share of world crude oil reserves, 2013



OPEC proven crude oil reserves, at end of 2013 (billion barrels, OPEC share)

Venezuela	298.4	24.7%	Iraq	144.2	12.0%	Libya	48.4	4.0%	Algeria	12.2	1.0%
Saudi Arabia	265.8	22.0%	Kuwait	101.5	8.4%	Nigeria	37.1	3.1%	Angola	9.0	0.7%
IR Iran	157.8	13.1%	UAE	97.8	8.1%	Qatar	25.2	2.1%	Ecuador	8.8	0.7%

Source: OPEC Annual Statistical Bulletin 2014.

Source: OPEC (2014)

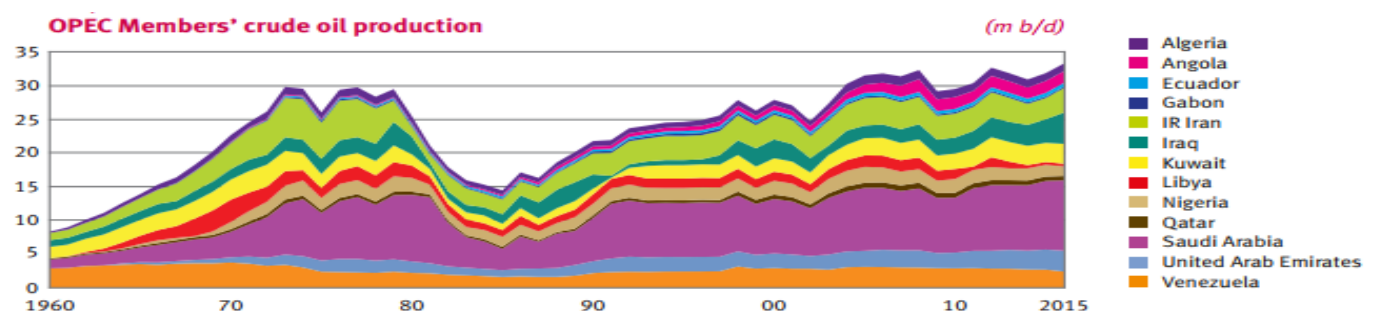
OPEC and its role should not be forgotten when analysing oil prices. It is a key player in the crude oil market and some may say that it is a ‘manipulator’ of oil prices. For example, Hamilton (2013) argues that OPEC’s decisions on production levels could significantly affect crude oil prices. This view is supported by Lin and Tamvakis (2010) and Barros et al. (2011) who studied the impact of OPEC decisions and they found that OPEC meetings created increased speculative interest causing higher oil price fluctuations and greater volatility. More specifically, Lin and Tamvakis (2010) noted that when there were no decisions about changes in production, it had no impact on oil price levels.

Loutia et al. (2016) also agree that OPEC's decisions have a number of effects on oil prices. For example, they note that decisions on production cuts and maintaining levels of production have greater influence on investors than when decisions about production increases are made.

Ansari (2017) studied OPEC, Saudi Arabia and the shale revolution after the global financial crisis. He questions the OPEC's decision taken in 2014, where production levels were not cut even when oil prices experienced decline. One reason offered can be to defend its market share, especially with growing new technologies entering the crude oil extraction market, such as shale fracking and new drilling methods, which have doubled crude oil production capacities in the US since 2012. Ansari (2017) further discusses the political influence of Saudi Arabia, which negotiated a deal with OPEC members in December 2016 that changes OPEC's previous strategy and sets up a new model, where OPEC acts as a single entity without regard to profit distribution among its members. OPEC's market power is also discussed by Golombek et al. (2018), who found evidence that OPEC had considerable market power between 1986 and 2016 through supply (production) levels, but that indications suggest that world GDP is the main driver of oil prices in the long run.

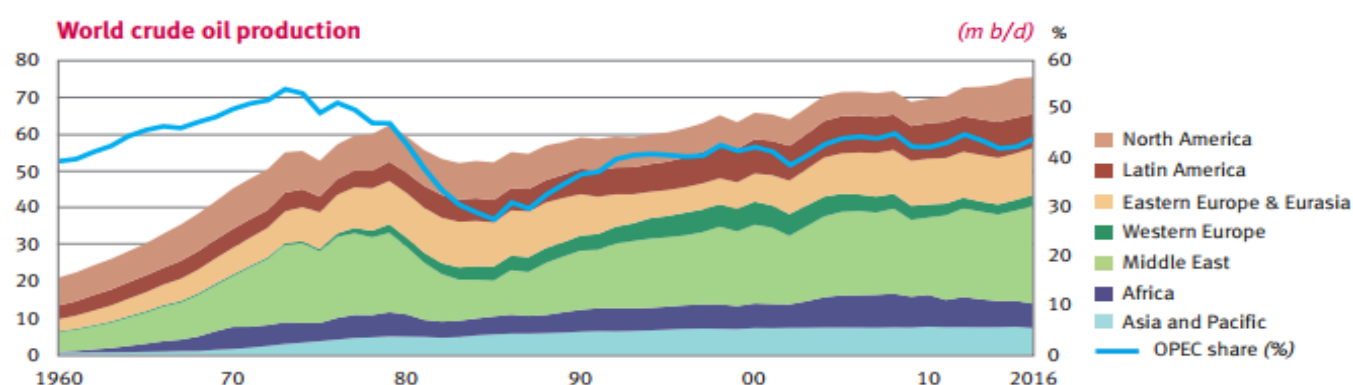
Figure 2.2 shows OPEC's crude oil production for 2016 and Figure 2.3 presents world crude oil production for the same year.

Figure 2.2: OPEC Crude Oil Production in 2016



Source: OPEC Annual Statistical Bulletin (2017)

Figure 2.3: World Crude Oil Production in 2016



Source: OPEC Annual Statistical Bulletin (2017)

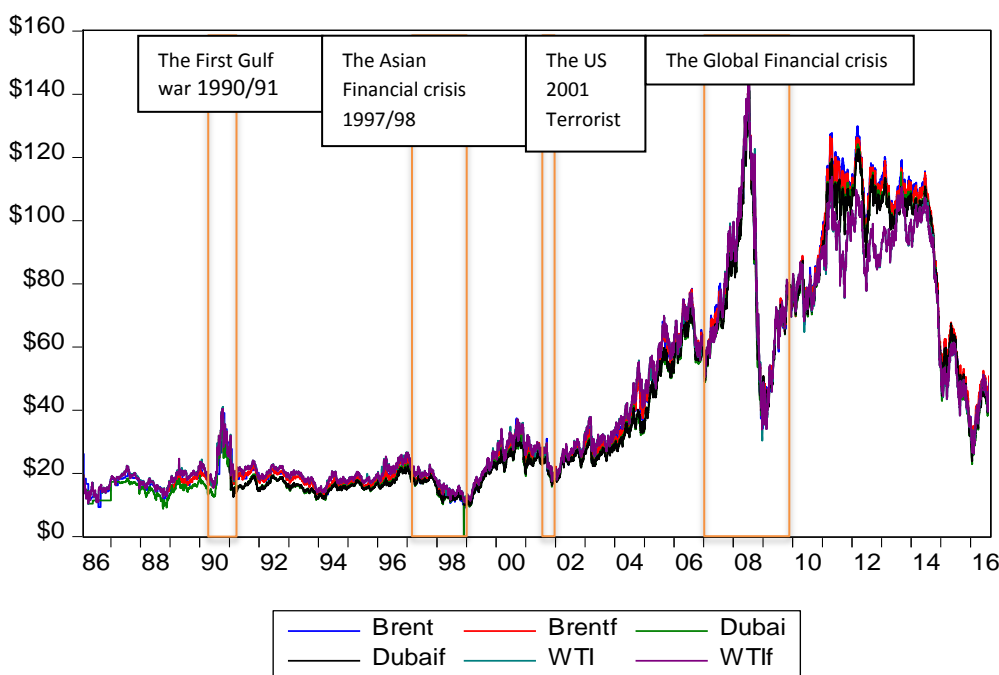
From the above information, it is apparent that OPEC's production levels are very high, and it seems to support the evidence that the OPEC has an influence on the settlement of oil prices. However, there are other factors impacting oil prices, which need to be considered when analysing oil prices. For example, Kilian (2009) and Kaufmann (2011) suggested that there are factors other than OPEC's decisions affecting investment decisions, speculators and hedgers, such as business cycles, natural disasters and the macro-economy as a whole. Lim et al. (2008) agreed and added economic and financial crises, terrorist attacks and other disasters to the list that are found to impact oil price volatility and the behaviour of oil market traders and speculators. The research findings seem to suggest that OPEC and speculation have an impact on oil prices. OPEC influences oil prices mainly through production decisions and speculators through their investment decisions. However, political unrest, economic cycles and other shocks appear to have a prime effect on oil price levels.

2.4 Major Shocks in the Oil Markets

Uncertainty in the oil market caused by repeated price jumps is a significant issue as it considerably increases the costs to businesses due to price uncertainty, which makes planning very difficult. Crude

oil as a commodity is not only impacted by supply and demand shocks, but also by business cycles and by the world economic and financial situation (Hamilton, 2014). This study is based on the events which had a major impact on oil price changes over the past decades. For example, the first Gulf War in 1990/91 caused oil prices to increase by 100 percent from \$20 to \$40 per barrel due to supply disruption initiated by Iraq invading Kuwait. The Asian financial crisis in 1997/98 also caused oil price levels to decrease from \$20 to \$13 per barrel arising out of a reduction in oil consumption in Asia, mainly by China as the major oil consumer. The US terrorist attack in September 2001 likewise had a negative impact on oil prices affecting air travel worldwide for a short period of time. Similarly, during the global financial crisis in the late 2000s the market experienced a rapid increase and sudden drop in oil prices caused by oil demand decline, mainly in construction and transport sectors, where oil prices reached the historical high of \$150 per barrel followed by a rapid drop to \$40 per barrel (Hamilton, 2009, 2011). Figure 2.4 represents the main oil price jumps highlighted above.

Figure 2.4: Major Shocks Affecting Crude Oil Prices



Source: Data from Thomson Reuters Datastream and graphical adding by the author (2017)

A similar trend is noted for all three benchmarks including spot and futures prices. The oil price volatility during the first Gulf War in 1990/91 and the US terrorist attack in September 2001 were caused by supply and demand shocks respectively in the oil market, and extraordinary oil prices changes were experienced during 1997/98 and late 2000s corresponding to the Asian financial crisis and the global financial crisis.

2.4.1 The First Gulf War

During the Gulf war, Iraq invaded Kuwait which caused oil supply disruption. The affected area accounted for nearly 9 percent of world oil production and both countries suffered huge financial losses. This caused their government revenues to decline and the world oil price to rise from \$20 to \$40 per barrel (Khan et al., 2018). This shock in the oil market lasted only for a short period of time and prices returned to their pre-shock levels quite quickly as the excess capacity of Saudi Arabia helped to restore oil production levels (Hamilton, 2013). A number of researchers studying oil markets dynamics have tried to identify structural breaks, which would help them highlight periods of extraordinary behaviour during this period. For example, Park and Ratti (2008) studied oil prices between 1986 and 2005 and found significant oil price changes in 1990/91, which corresponds to the first Gulf War period. Salisu and Fasanya (2013) also examined Brent and WTI oil prices from 1986 to 2012 and identified a structural break relating to the first Gulf War. Likewise, Morales and Gassie-Falzone (2014) found multiple structural breaks in oil markets using the Bai-Perron test. They analysed this in connection with the US stock markets and established connections between volatility persistence and oil prices during times of structural changes. Similarly, Charles and Darné (2014) examined oil prices between 1985 and 2011 and found periods with high price changes in 1990. The findings suggest that the level of uncertainty is very high during this period, which could have a major impact on econometric testing and the estimated results. For this purpose, the analysis of this

thesis includes the Gulf war as one of the major shocks to be examined as the research outcomes will offer interesting insights when understanding crude oil behaviour over periods of significant market instability.

2.4.2 The Asian Financial Crisis

The Asian financial crisis in 1997/98 started in the currency market, where the collapse of Thai baht drove Thailand nearly bankrupt. The economic slowdown in Thailand impacted other Asian countries and together with China, the key oil consumer, caused lower demand followed by a decrease in oil prices from \$20 to \$13 per barrel. This corresponds to Hamilton's (2003) findings where he suggests that during the Asian financial crisis oil prices dropped by 50 percent during 1997 and 1998. This regional crisis had an impact on oil prices for a short period and they returned to pre-1997 levels by 1999. Ozdemir et al. (2013) studied Brent spot and futures prices between 1990 and 2010 and found many minor structural breaks together with some major breaks. They pointed out that the Asian financial crisis period affected the oil market and the global economy and from 1998 they noted that the oil market became more volatile. Also, Wang and Wu (2012) and Wang et al. (2016) suggested that during the Asian crisis oil prices were impacted by lower oil demand, which is a reason for including this oil crisis in this study, as it allows us to test the effect on both spot and futures prices. Similarly, between 1993 and 2009 Morales and Andreosso-O'Callaghan (2017) identified the Asian financial crisis as a significant period in the Brent and WTI oil markets during which oil prices were affected. Their findings show that the uncertainty during shocks may impact government decisions concerning energy policies.

2.4.3 The US Terrorist Attack

In September 2001, the terrorist attack on the World Trade Centre in New York caused a significant decline in oil prices. The Islamic terrorist group Al-Qaeda used two American Airlines planes, which crashed into the Twin towers, and a third plane which crashed into the Pentagon in Virginia. A fourth plane was directed to Washington D.C, but ended up crashing in a field in Pennsylvania. This incident caused great panic and fear of air travel, which decreased demand for oil and oil prices fell by 35 percent by November 2001, but the OPEC decision to cut oil production quotas in 2002 pushed the prices up again. Fernández (2004) analysed the effects of the 9/11 2001 attack on oil prices and found a breakpoint corresponding to the attack. Sadorsky's (2012) study on oil price volatility between 2001 and 2010 revealed large volatility spikes during September and November 2001. This finding is consistent with the findings of Wang and Wu (2012) and Morales and Andreosso-O'Callaghan (2014). Wang et al. (2016) also found substantial oil price changes during this period followed by a quick recovery driven by strong economic activity and OPEC's decision to cut production levels. As the oil price decrease of 35 percent was significant and above normal, there is good reason to include this oil demand shock for analysis.

2.4.4 The Global Financial Crisis

In late 2000s, the turmoil during the global financial crisis originated in the US subprime market. This caused substantial instability in financial markets, with spillover effects to oil markets. Oil prices increased to \$150 per barrel by July 2008 and fell below \$40 by the end of 2008. This was due to stagnant oil supply and lower demand for oil. Salisu and Fasanya (2013) and Charles and Darné (2014) found high oil price changes with structural breaks during December 2008 and January 2009 matching the global financial crisis period. Equally, Liu et al. (2013) identified the presence of spikes in the series in late 2008 triggered by the crisis. Ozdemir et al. (2013) recognised structural breaks in

November 2008 for Brent spot and futures prices and suggested that the break should be incorporated in econometric testing as the outcomes can be considerably different. Furthermore, Zhang and Wang (2013), Zhang et al. (2015) and Zhang and Li (2016) found shocks in oil prices in late 2008, which affected spot and futures oil prices. This suggests that the era of the global financial crisis should be monitored and carefully analysed for forecasting purposes and included as one of the major shocks in the oil market.

Taking into account the studies conducted by researchers in this area, there is a need to fill the gap and analyse major events throughout the history of oil market to understand oil market behaviour during such periods, and which could occur in the future again. Analysis looking at multiple crises periods has not been considered as yet, which brings value to this line of research. It addresses important points, which could reduce risk during crises in the future as this thesis outcomes offer insights that are useful for decision making processes through cost reduction associated with oil price risk and uncertainty.

2.5 Crude Oil Spot and Futures Prices

2.5.1 Lead and Lag Relationship

The lead and lag relationship between spot and futures prices is a widely studied topic as it can help investors to decide which price to follow during decision-making processes. It can also discover any potential arbitrage opportunity between spot and futures prices. A study conducted by Kim (2015) suggests that the lead-lag relationship between crude oil spot and futures prices is changing over time depending on macroeconomic events, but the details for particular periods are needed. This thesis

will help to detect which price leads in stable and crises periods, bringing valuable information to oil market players.

Likewise, the level of oil prices is very important. If oil prices are too high, oil importing countries could experience growth rate decline as the cost of energy will put downward revenue pressure on industries having oil products as their key cost drivers (Priog, 2005). Equally, Wang (2013) noted that oil price shocks and rising oil prices seem to slow down economic activity. Other researchers argue that current and future supply and demand levels are important for oil exporting and importing countries as they influence economic activity (Zhang and Wang, 2013; Forni et al., 2015). They noted that it is not an easy task to estimate future demand and supply levels when market conditions are uncertain with frequent changes. Moreover, Ozdemir et al. (2013) pointed out that crude oil markets are affected by many economic and non-economic factors such as supply and demand shocks, local and global events, and geopolitical threats. Both spot and futures prices were hit by the above events causing abnormal increases and falls in prices.

The dynamics of spot and futures oil prices and their relationship raises queries between these two prices leading positions. For example, Zhang and Wang (2013) claim that oil futures prices are a better crude oil price indicator than spot prices. They argue that crude oil futures are traded worldwide since 1983 making it the largest and most traded futures market, which helps economic growth and international financial stability. This is consistent with Alquist and Killian's (2010) findings where they point out that low transaction costs and wide use of short selling mechanisms help the futures market to react quicker to new information than the spot market, which makes futures prices more efficient. In contrast, Pindyck (2001) examined the effects of futures trading on spot prices and found that the existence of futures markets improved the quality of information flowing to the spot market, where spot prices quickly reflected the changes. Therefore, he found no

evidence of one price dominating the other and concluded that both prices are similarly important and sensitive to outside factors, which is the first step to be considered in this research study by establishing the relationship between crude oil spot and futures prices from the long and short run perspective.

2.6 Oil Price Dynamics

2.6.1 Long Term Relationship

Numerous authors have tested the relationship between spot and futures prices (Schwarz and Szakmary, 1994; Bekiros and Diks, 2008; Wang and Wu, 2013; Mehrara and Hamldar, 2014; Ding et al., 2014). Kahneman and Tversky (1979) looked at decision making processes under risk and found strong relationships between spot and futures prices during downturn periods, but not as strong during periods of oil price increases. This initiated the idea of analysing spot and futures prices during crises and tranquillity periods in this thesis, where the differences between shocks effecting increases or decreases in oil prices could highlight the main differences in the dynamics of oil prices. It also provides the starting point of the analysis to understand the relationship between oil spot and futures prices. Wang and Wu (2013) reviewed the long term relationship between crude oil spot and futures prices using monthly and quarterly data for the WTI market. They applied the Johansen cointegration and VECM models from 1986 to 2011. Their finding shows significant evidence of a cointegration relationship, which suggests that both prices should be monitored during decision making processes. On the other hand, they found that for higher frequency data, such as weekly data, futures prices can drive the spot price. Therefore, the analysis of spot and futures oil prices during long term periods needs to be tested for the dataset proposed in this study to establish all significant outcomes supporting or rejecting Wang and Wu's (2013) findings for specified daily data. Strong

evidence of spot and futures prices cointegration was found by Mamatzakis and Remoundos (2011) using daily data from 1990 until 2009, which proves that long run relationships can be used as a crude oil behavioural indicator. Zhang and Wang (2013) found similar results using daily data from 2005 to 2011, which establishes the existence of a long run relationship. However, this needs to be analysed further to distinguish any differences in outcomes for different sub periods, and in particular during episodes of shocks in the oil market. The outcomes for various shocks could offer important proof of variations in the lead-lag relationship and dynamics of oil markets.

Early research conducted by Schwarz and Szakmary (1994) indicated that futures markets may dominate spot markets in the oil discovery process. Their finding was confirmed by Gulen (1998) who analysed the crash in 1986 with the help of the Perron (1989) structural break test. He states that futures prices are used as a benchmark worldwide and therefore they are important for decision making. The long term relationship between crude oil spot and futures prices was analysed more recently by Lee and Zeng (2011) and Chen et al. (2014). Their analysis covers the period 1986 to 2012, where the Johansen cointegration test showed that spot and futures prices for WTI are cointegrated and the need to apply structural breaks is highlighted due to high volatility changes in the oil markets as any significant structural changes in the series could affect the econometric outcomes. By applying the structural break tests, the time series are split according to identified break dates, which are then tested separately to avoid spurious results. Their findings must be taken into consideration in this research, whether it holds or changes for various sub samples using daily data. The next subsection continues with the discussion of the short run relationship between crude oil spot and futures prices.

2.6.2 Short Term Relationship

The short run relationship between crude oil spot and futures prices was analysed by authors such as Bekiros and Diks (2008), Candelon et al. (2013) and Ding et al. (2014). The aim of the study by Bekiros and Diks (2008) was to test if one price leads the other price in the short run. In their analysis they examined two data samples. The first sample starts in October 1991 up to October 1999 and the second sample runs from November 1999 to October 2007. Their finding shows that neither of the prices leads or lags consistently over time. Therefore, both prices should be monitored at the same time and neither of them can be taken as the oil price indicator. Candelon et al. (2013) also examined the short term relationship between spot and futures oil prices using weekly data during rises and declines in the market applying the Granger causality test. Their study involved a number of crude oil markets, 32 altogether. They found that Brent and WTI are the main benchmarks, where WTI is dominant in extreme oil price rises. They came to the same finding as Bekiros and Diks (2008) that both prices are important price setters during turbulent times. This is the fundamental reason that justifies the need to examine both prices in this thesis to understand how price dynamics between oil spot and futures indices might change over crises periods.

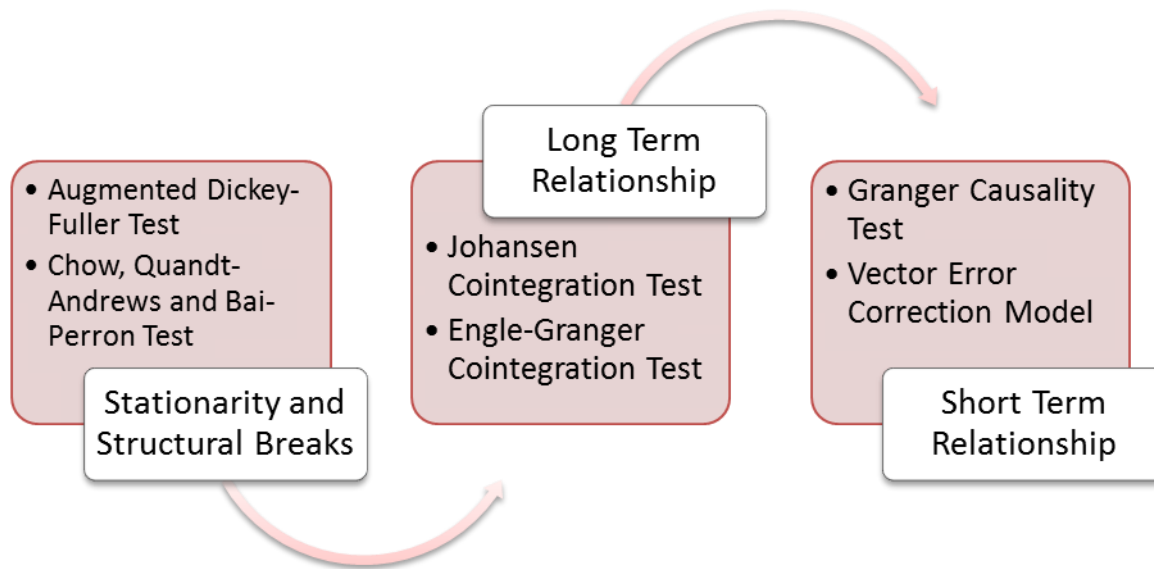
On the other hand, a more recent study by Ding et al. (2014) suggest that at some points in time, future prices may work as the underlying mechanism of spot prices, especially in periods with higher oil returns. The explanation for that can be that higher returns increase speculation in the futures markets, which increases futures prices. The spot price then follows the futures markets' price levels and spot prices rises accordingly. They conducted their research with WTI weekly data from 1996 to 2012, noting that oil prices started to increase in 2003 and reached a peak point in summer 2008. Ding et al. (2014) also argued that increases in futures oil markets speculation is the reason for upward trends in oil markets. This is consistent with Singleton (2013) who also claims that speculation in futures markets increases oil spot prices. This would mean that futures prices would

lead spot prices and have a bigger impact on oil price formation. However, this argument is countered by Hamilton (2009; 2014) who believes that crude oil supply and demand is the main oil price setter. This controversy needs to be analysed further to clarify the dynamics of oil price relationships.

2.6.3 Brent Long and Short Term Relationships

The first paper developed as part of this research thesis studies the long term and short term relationship between Brent crude oil daily spot and futures prices between 1988 and 2013. This period was selected to include two major crises impacting oil markets. The first one is the first Gulf War in 1990/91 and the second is the global financial crisis in 2008/09. The two periods were split with the help of structural break tests and the purpose is to examine the relationship over the whole period and also before, during and after the two crises, to provide an indication of the lead-lag relationship between spot and futures prices. This could offer important information to oil market participants through monitoring the markets and identifying the leading price during stable and shock periods. Econometric methodologies (Johansen cointegration test, Engle-Granger, Granger causality and VECM models) together with multiple Bai-Perron structural break tests were identified with the help of existing studies that tested the long term and short term lead-lag relationship to gather robust data of the outcomes, as shown in Figure 2.5.

Figure 2.5: Paper 1 Methodology



Source: The author (2017)

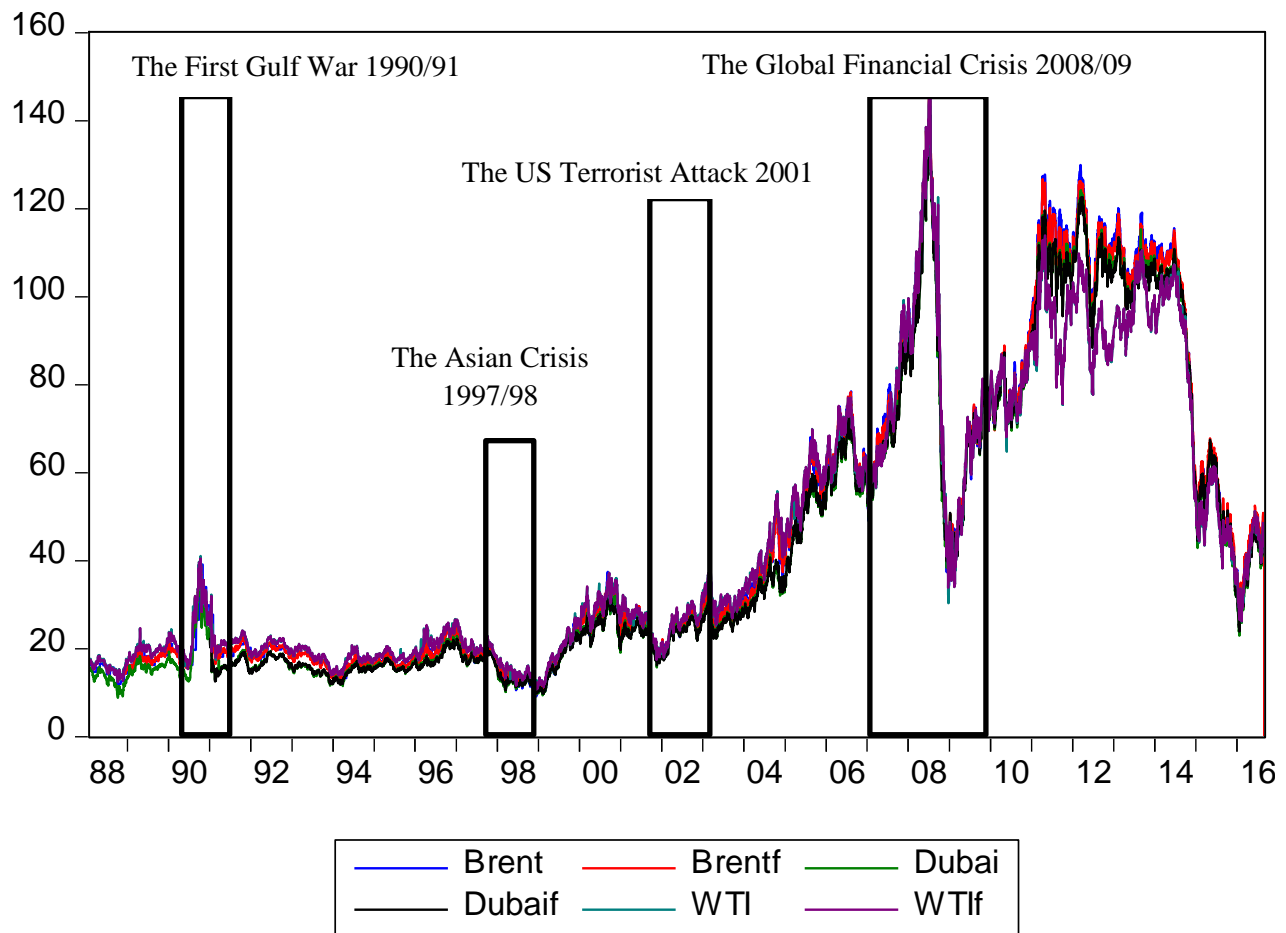
The reviewed literature shows evidence of a lack of research considering the proposed time period, and this research gap is being addressed as part of this thesis, and making it an initial contribution to the field. The application of the methodologies for the pre-crises, crises and post-crises periods helps to find the leading price or changes in leading price during turbulent times for oil spot and futures markets. The following section discusses speculation and the impact of OPEC's decisions in the oil market as it decides on the production levels, which indirectly affect oil prices.

2.7 Structural Breaks and Their Impact on Oil Series

A typical feature of oil markets is frequent oil price volatility. At times of shocks, political instabilities and economic cycles, oil price changes can exhibit significant fluctuations that could advance into a structural break. A structural break means that there is an unexpected change or a shift in oil prices, which can impact econometric estimates outcomes and lead to unreliable/spurious

results. Therefore, researchers try to avoid the impact of structural changes on econometric testing and include structural break analysis (Charles and Darné, 2014) or they divide the tested period into sub-periods according to shocks or crises (Bouri, 2015). Researchers agree on the importance of it in econometric modelling (Lee et al., 2010; Salisu and Fasanya, 2013; Charles and Darné, 2014; Mensi et al., 2014). For this reason, the need for structural break analysis and inclusion into econometric testing for further examination is important. Figure 2.6 illustrates some of the jumps (potential structural breaks) in crude oil history, which affected oil spot and futures prices.

Figure 2.6: Historical Oil Spot and Futures Prices



Source: Thomson Reuters DataStream and Eviews 9 (2017)

Therefore, researchers should pay more attention to incorporate the analysis of breakpoints while testing oil markets. For example, Charles and Darné (2014) analysed volatility persistence between 1985 and 2011 with a focus on shocks during this time. They found that oil price forecasting is affected by structural breaks, and these breaks should be included in the analysis to improve econometric testing. Likewise, Lee et al. (2006) and Narayan and Narayan (2007) were some of the first authors to find structural breaks as an important issue in volatility testing, adding the need to split data samples according to the identified breakpoints. Furthermore, Morales and Andreosso-O'Callaghan (2014, 2017) pointed out the necessity of structural break inclusion using the Bai-Perron or the ICSS structural break tests. Ma et al. (2017) applied the rolling window approach to reduce and capture the impact of structural breaks. They found this approach a better forecasting predictor than data analysis looking at the whole tested period at once, as the results for long periods could omit or distort significant results of specific events. Therefore, it is important to divide tested periods according to structural breaks or to carefully select window sizes for the implementation of moving/rolling window approaches.

Another way of dealing with significant changes in time series was introduced by Ahmadi et al. (2016) who investigated oil price shocks and volatility using the structural vector autoregressive (SVAR) model from 1983 until 2014. The discussion includes oil specific shocks together with macroeconomic situations where they split the data sample into two sub periods. The first sub period includes data from 1983 until May 2006 and the second sub period starts from May 2006 until 2014. The reasoning behind their selection is to divide the sample into a period prior to the global financial crisis and a period including the global financial crisis. Their main finding shows that various shocks influence the volatility outcomes in different magnitudes which relates to both chosen sub periods. Moreover, their research includes the impact of oil price shocks and volatility on agricultural and metal commodities. The results suggest that oil price shocks influence the other commodity markets

during shocks, which is even more evident after the global financial crisis in 2008. However, each commodity market must be analysed separately to be able to detect the magnitude of the oil price shock for the specific time period.

The need to understand price dynamics during times of distress requires identification of structural break analysis to split the data sample to consider specific periods of turmoil. It is important to include this type of analysis and extend the existing research by examining oil price dynamics during periods of significant oil price changes. This will help to eliminate the high costs associated with oil price risk during times of uncertainty. The next section discusses oil price volatility and persistence of shocks as it has the ability to capture the magnitude of significant oil price changes.

2.8 Oil Volatility and Forecasting

Oil price fluctuations and their volatility changes depend on supply and demand levels, business cycles, levels of speculation, political activities such as wars, and economic and financial crises. Investment and strategic decisions depend heavily on oil price levels and volatility phases. Increased levels of volatility and uncertainty lead to higher price risk in the oil market. Ferderer (1996) analysed volatility in the oil market and found that shocks have an asymmetric impact on oil prices and the economy. That means that increased oil volatility has a negative impact on the economy as there is higher uncertainty in the oil market. This is consistent with an early study conducted by Mork et al. (1994) who also found significant asymmetries between oil price volatility and the macroeconomy affecting the GDP of seven OECD countries. Sadorsky's (1999) findings suggest that oil price changes affect economic activity, but there is little impact of economic activity on oil price levels. During times of greater oil price volatility investors tend to hedge more against this risk to be able to plan their operations and help them with decision making processes (Sadorsky, 2006; Salisu

and Fasanya, 2013; Morales and Andreosso-O'Callaghan, 2014). All events impacting crude oil volatility make it hard to predict oil prices, which increases uncertainty. This uncertainty applies to spot and futures markets, which suggests the need of studies applying analysis to both spot and futures prices. Crude oil volatility was studied by a number of researchers to be able to understand its behaviour (Oberndorfer, 2009; Zhang and Wang, 2013; Charles and Darné, 2014; Wang et al., 2016). Similarly, Ozdemir et al. (2013) examined Brent crude oil spot and futures prices from 1991 until 2011 and found that volatility persistence was very high for both prices. They also pointed out that spot and futures prices can behave unpredictably in the long run indicating no arbitrage opportunities with little possibility for speculation.

Morales and Andreosso-O'Callaghan (2017) analysed oil markets during the Asian and Global Financial Crises using the T-GARCH (1,1) volatility model and Bai-Perron structural break test. They applied the econometric models to daily data for the period starting in 1993 until 2009. They found that during the global financial crisis volatility persistence had a bigger impact on oil markets than during the Asian crisis. They explain that this is due to a higher magnitude of the effect on the world economy than the regional impact associated with the Asian financial crisis. This research finding suggests that not only the triggers of the crises, but also the geographic location, play a big part in analysing oil markets behaviour. Moreover, significant structural changes were evident in both cases. For this reason, the analysis of this thesis includes the US and the Middle East benchmarks together with the European benchmark to provide a broader examination of the world oil markets.

Bagchi (2017) conducted a volatility analysis for multiple crude oil markets, namely for BRIC countries, which are Brazil, Russia, India and China. The methodology adopted in this research includes the asymmetric power ARCH (APARCH) model. This approach considers the long memory

behaviour, speed of market information, leverage effects and asymmetries. The author applied this method to weekly closing prices from 2009 to 2016. The data excludes the global financial crisis period and considers the post-crisis period only. The finding shows that there are evident asymmetries between good and bad news in the market. This essentially means that negative shocks will create greater volatility in the oil markets than positive shocks. More recent studies examining oil market shocks with connections to financial markets are Broadstock et al. (2016), Ftiti et al. (2016), Sanusi and Ahmad (2016) and Oztek and Ocal (2017). Broadstock et al. (2016) point out that oil shocks affect the financial sector as inflation rises thereby increasing businesses costs, which increases pressure on many firms and industries. Therefore, high volatility increases uncertainty in the oil market, which puts pressure on the economy and financial markets. Phan et al. (2015) also discuss the energy price shocks and their negative effect on rising inflation. They indicate that there are trade-offs between risk and return with the possibility of hedging spot and futures contracts in times of instability. Similarly, Cotter and Hanly (2010) examined hedging strategies in energy markets in the context of risk management and risk aversion approaches. Their findings show that hedging depends on the economic situation and time horizon, where risk-averse businesses tend to hedge for longer periods during times of crises associated with increased uncertainty. Their discovery is relevant to investors in energy markets. Therefore, understanding dynamics between spot and futures prices adds value to research looking at oil price behaviour during shock periods to help decide time horizon and strategy for hedges depending on the type of crises and their impact on businesses.

Another interesting study by Andriosopoulos et al. (2017) investigated the oil markets with connections to financial markets in 'troubled' European countries including Greece, Portugal and Ireland. The volatility part of this paper examined the nature and effects of energy price volatility. The GARCH models were applied to data starting in 2004 and ending in 2014. The evidence shows

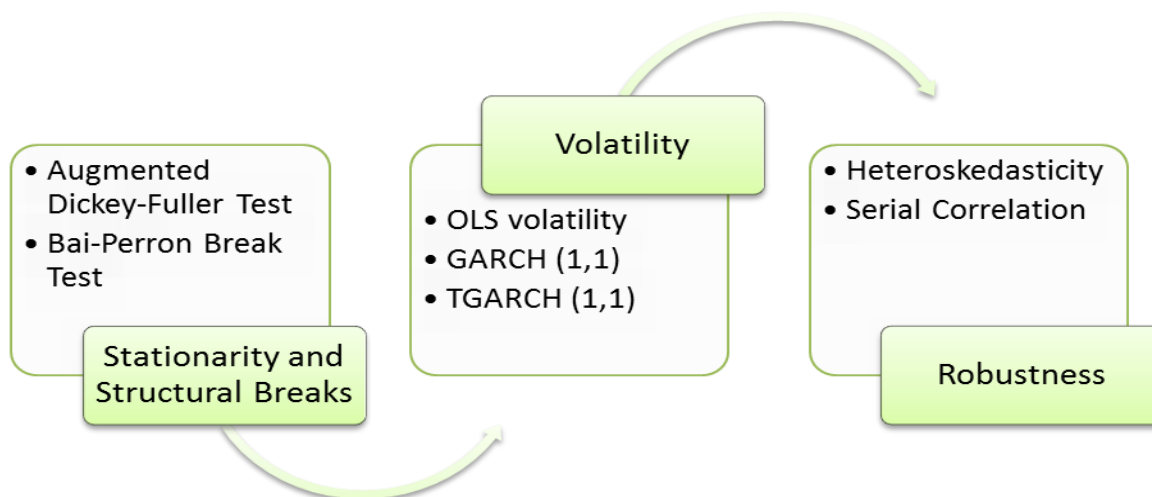
that there are apparent changes in energy volatility during the financial crisis for the named European countries, which was established by splitting the sample into three sub periods - pre-crisis, crisis and post-crisis. In line with recent studies, Ma et al. (2017) analysed oil futures volatility, where they tried to put forward a new modelling approach, which would include a significant jump component in the heterogeneous autoregressive model of realised range-based volatility (HAR-RRV). The research shows that their improved methodology of oil price volatility improves the econometric testing significantly as it includes the jump component, which is needed in analysing oil prices. Moreover, their new approach using 5-minute high frequency data for one-month futures highlighted the strength of GARCH- type components, which showed the most accurate volatility forecast in the oil futures markets.

Haugom and Ray (2017) also examined the crude oil volatility for futures markets using high frequency data for Brent crude futures oil market traded on the Intercontinental Exchange (ICE). The sample period starts in 2006 and ends in 2016 giving over 2,500 trading days. The main attention was focused on volatility, liquidity, speculation and hedging activities. The outcomes showed that speculators and hedgers have a very different effect on oil volatility and returns distribution. Speculation activity and speculative trading goes in hand with high oil price volatility. On the other hand, hedgers and hedging activity have the reverse effect, where volatility is reduced when more hedgers enter the oil market. This is even more evident during shock periods affecting oil volatility. Similarly, Antonakakis et al. (2018) analysed oil volatility in connection to hedging and portfolio diversification between 2001 and 2016 for WTI and selected oil and gas corporations using daily closing prices. They found high volatility spillover connections between WTI and oil companies during the global financial crisis between 2007 and 2009 compared to the pre-global financial crisis period, which suggests the importance of closer examination of crises periods affecting crude oil markets.

2.8.1 Brent Volatility

The second paper of this thesis investigates the volatility of Brent crude spot and futures prices from 1988 to 2013. Standard and settled approaches are combined with more advanced volatility models that were used to generate information for the first Gulf War in 1990/91, the Asian financial crisis in 1997/98, the US terrorist attack in 2001 and the global financial crisis in 2008/09. See Figure 2.7 below for the testing approach to be taken.

Figure 2.7: Paper 2 Methodology



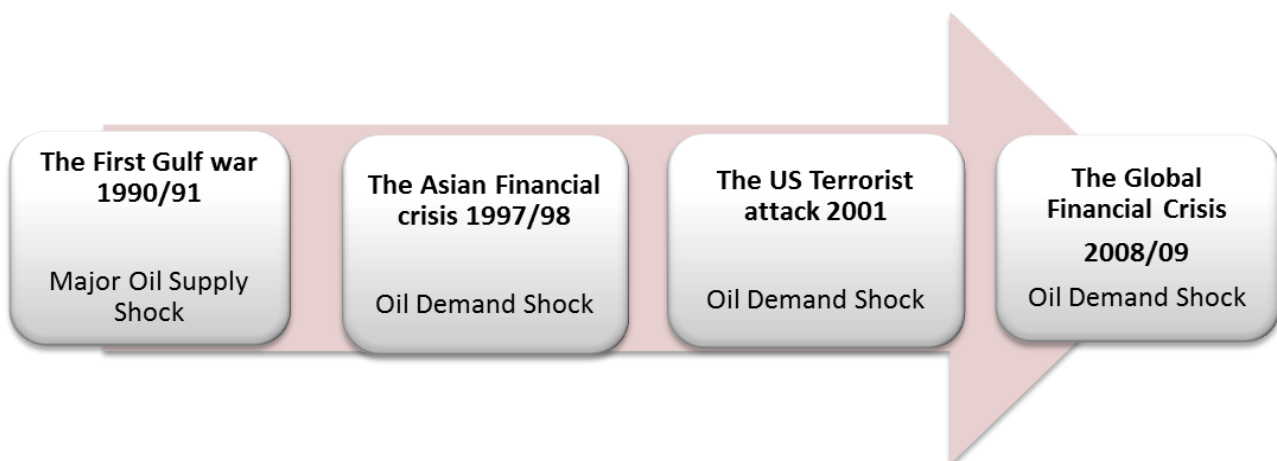
Source: The author (2017)

The analysis employed structural breaks to split the sample into stable and crises periods to find levels of volatility persistency and volatility spikes for both prices. Specifically, more attention is paid to the triggers of each crisis to find potential similarities or differences between the shocks, as the fundamentals of supply and demand may affect oil prices differently than economic or financial reasons. The outcomes of the volatility analysis can provide information on oil price risk as the magnitude of volatility changes for various shocks could highlight behavioural similarities

depending on the specific trigger. Therefore, future behaviour during times of high changes could be connected and used for decision making and future planning.

The following subsections offer some insight on the analysis looking at four major shock events, which had a major impact on oil prices behaviour (see Figure 2.8 below). The main crises were identified with the help of structural break analysis. The studies in the field also helped to clearly identify a lack of existing research that looks at different episodes of market uncertainty that generated disruption in the oil market.

Figure 2.8: Major Episodes of Shocks in the Oil Markets



Source: The author (2017)

2.9 Market Efficiency

Over the past decade there have been significant controversies around the Efficient Market Hypothesis (EMH) theory introduced by Fama (1965), and its application to markets. EMH theory is based on a principle that future prices cannot be predicted by past prices, which means that prices follow a random walk and no information based on past price behaviour can predict future trends. In

other words, excess price returns are not based on past price movements. This has a number of implications, mainly for academics when analysing financial theories, but also for policy makers, investors and their strategies. When looking at oil prices, it is essential to test and identify if and when the oil markets are efficient or inefficient as it could highlight periods of potential need of changing such strategies in order to maximise profits and reduce oil price risk uncertainty.

The reason for testing this theory became more relevant with increased speculation in the markets and the inclining belief in the behavioural finance stream. The founder of EMH, Eugene Fama, won a Nobel prize for economics in 2013 together with Robert Shiller - the financial behaviourist, who argues that the EMH theory is only half true and that the markets show behavioural signs over time. This triggered the idea to test if oil prices follow a random walk theory under the EMH or show signs of irrationality in their price behaviour. This is very important in the analysis of crude oil markets to ensure efficiency from investors and policy-makers viewpoint. The key reason to test the EMH is to examine the controversies between different schools of thought. It is also motivated by the different dynamics exhibited by oil prices during times of high uncertainty that could lead towards significant changes in terms of market efficiency.

The analysis of crude oil prices over time shows that there have been numerous destabilising events in the oil market, which had a great impact on oil prices. It has been mainly, political unrest, natural disasters, OPEC decisions and financial and economic distress which caused the biggest changes in oil price levels. Davidson (2008) and Kaufmann and Ullman (2009) pointed out that these types of events have contributed to oil markets instability and triggered some of the key jumps in oil prices behaviour. Instability in the oil markets increases market uncertainty, which is followed by higher oil price volatility and lower confidence in the oil market. Higher volatility also increases risk and makes it harder to predict future oil behaviour. Kaufmann (2011) added that increasing speculation is

another cause of instability in oil markets together with the fundamentals of supply and demand levels. Therefore, the randomness of oil markets should be analysed and examined for the periods of uncertainty and compared to periods with stable behaviour. This points to another theme for analysis covered in this thesis and which examines oil market efficiency during crises. To do that, the existing literature findings on the random walk hypothesis under the EMH introduced by Fama (1965, 1970) are reviewed in the context of oil markets.

Charles and Darné (2009) studied Brent and WTI efficiency for daily spot prices between 1982 and 2008 using the variance ratio tests. Their main results suggest that the Brent market follows a random walk, while the WTI market is inefficient between 1994 and 2008. They explain that this may be due to the deregulation process, which occurred in 1994. Similar findings showed in research conducted by Serletis and Andreadis (2004). Controversially, Tabak and Cajueiro (2007) found the WTI market to be more efficient than Brent between 1983 and 2003 using the rescaled range Hurst analysis. Gu et al. (2010) also analysed WTI and Brent between 1987 and 2008 by implementing the multifractal de-trended fluctuations and found that both markets became more efficient in the long run. On the other hand, Wang and Wu (2013) suggested that futures oil markets are inefficient, where inefficiency is more evident in the long run than in the short run. The outcomes of these studies initiate the need to consider major events in the oil market and also to carefully choose time periods and sub-periods for the analysis.

Ozdemir et al. (2013) suggested that Brent spot and futures prices are unpredictable, which means that there is no arbitrage opportunity. This supports the random walk hypothesis under EMH. They used monthly data for Brent spot and futures prices in their analysis, which suggests that the results might be dependent on data frequency as lower frequency data does not include daily jumps in the series. Therefore, it is important to carefully identify the data frequency needed for specific analysis.

Frequent crude oil price changes are typical for the oil market and thus daily data seem to be more relevant for in-depth study during multiple crises periods. The reason for this is that some crises periods might last for a shorter time than others and monthly data would not suffice for the analysis. This reasoning is consistent with Charles and Darné (2009) and Narayan et al. (2010).

Lean et al. (2010) examined daily spot and futures oil prices for WTI from 1989 to 2008 using the mean-variance and stochastic dominance approach. They found that with increasing oil price fluctuations, investors tend to rely more on derivatives markets. Their finding suggest that speculation in oil futures stabilises the oil market. Similarly, Kim (2015) pointed out that oil futures prices have a positive impact on past price changes, which means that futures markets should improve oil price efficiency over time. This is in contrast with Hamilton (2009), Fattouh et al. (2013) and Hamilton (2014) who believe that speculation through futures markets has no impact on oil prices. The more recent study of Gu and Zhang (2016) applied multifractionality analysis in their crude oil market efficiency work. They include supply and demand levels, geopolitical events, natural disasters and economic activities in their testing. They also include speculation as an influential player in oil price settings and argue that speculation can stimulate oil prices in two ways. Firstly, speculators can invest in the spot market with the real commodity by buying oil at low prices and selling it at high prices. Secondly, speculators can speculate in the futures markets, which is more common. For that reason, the analyses of both spot and futures prices are needed to answer their behaviour during turbulent times. Based on the literature findings, the outcomes for oil market efficiency should differ for spot prices compared to futures prices results, especially during shock periods.

Other authors such as Jiang et al. (2014) have studied the efficiency of crude oil markets. They examined daily WTI futures prices from 1983 to 2012 applying the Hurst index and bootstrapping

techniques to test the weak form of market efficiency. They examined the whole dataset and also both two and three sub-samples in their study. The findings for the whole period shows that the WTI futures market is efficient, but when they split the sample into three sub-periods based on the Gulf war and the Iraq war, efficiency was reduced during the Gulf war. The two sub-periods were split based on the North American Free Trade Agreement in 1994, and showed that the market is inefficient. These findings suggest that at times with increased volatility oil price efficiency is impacted. Including three key oil benchmarks, during major shock periods, could offer interesting results for spot and futures oil markets efficiency. To the best of the author's knowledge, this is an aspect that has not been addressed by existing studies and that this research seeks to address. Longer time periods also include more oil price jumps and these need to be examined carefully when analysing testing outcomes as they can affect efficiency patterns.

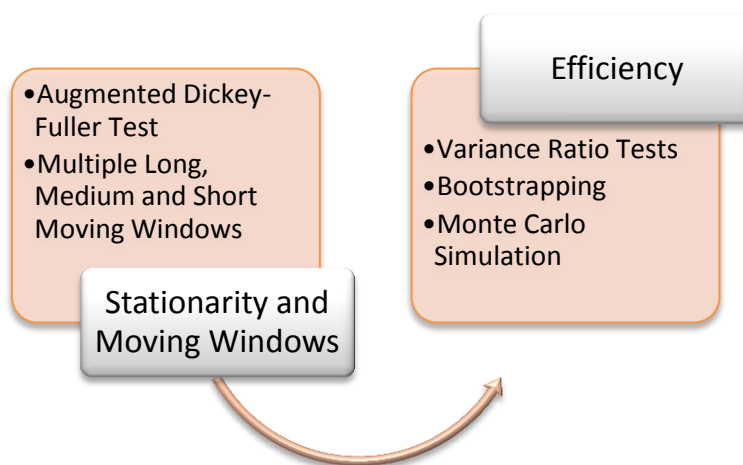
2.9.1 Brent, WTI and Dubai Efficiency

Considering the outcomes of the reviewed literature, the third research paper of this study focuses its attention on testing the random walk hypothesis under the Efficient Market Hypothesis to explore the oil market efficiency for Brent, WTI and Dubai crude oil spot and futures markets. The thesis includes the European benchmark (Brent) as in previous papers, but it also contains the US benchmark (WTI) and the Middle-East benchmark (Dubai crude) as the key geographic crude oil benchmarks. The data sample starts in 1986 and ends in 2016 and includes major crises periods affecting oil markets during the first Gulf War in 1990/91, the Asian financial crisis in 1997/98, the US terrorist attack in 2001 and the global financial crisis in 2008/09.

The analysis of the third paper brings in an improved econometric approach by introducing moving window methods that were identified as valuable techniques when looking at market dynamics, as

they help to expand the scope of this research to investigate the efficiency of crude oil markets for different sub-periods in a dynamic context. The long, medium and short term windows are examined to pick up for any possible arbitrage opportunities. If the tests show that markets are not efficient in certain time periods it will highlight the exact time window. For example, times of crises or periods with high speculation activities may indicate the existence of certain trends, which could make oil prices more predictable and less efficient than during tranquil periods. However, multiple changes in oil markets may cause spurious results, which are reduced by medium and short term moving windows that would allow cross checking the research outcomes. The methodology flow chart is presented in Figure 2.9 below.

Figure 2.9: Paper 3 Methodology



Source: The author (2017)

The existing research analysing crude oil market efficiency offers useful information about oil price behaviour, which gives the base for the econometric modelling strategy for this research looking at the times of crises in order to reduce uncertainty and price risk.

The analysis of the reviewed literature shows that periods of shocks and crises are included in most oil market studies, but are not the main point of interest in econometric modelling over long time periods. Therefore, this thesis goal is to include major shock events affecting oil markets, and conduct long term, medium term and short term relationships analysis between crude oil spot and futures prices, which will help to understand their dynamics over time. It also includes volatility analysis to examine oil price changes during turbulent times. Finally, the efficiency analysis helps to understand if oil prices follow a random walk hypothesis under the EMH during such events. This will fill the research gap looking at the major crises periods in oil markets, with the help of three research papers investigating each one of the proposed research themes. The outlined research framework brings interesting insight regarding the lead-lag relationship in the context of economic and financial crises, which is an area of study that has not received sufficient attention.

2.10 Summary

The literature review started with the presentation of oil markets and historical behaviour of spot and futures prices, the role of OPEC and discussion of major shock events affecting oil markets. Understanding the dynamics led to the three themes under this research: 1) the long and short term relationship between spot and futures prices, 2) volatility and 3) efficiency analysis. The literature also assisted with the econometric methods applied in this crude oil analysis, which was selected after careful examination of the existing literature to fit the research sample. The main models include the Johansen cointegration test, Engle-Granger test, Granger causality, VECM model, OLS for volatility, GARCH (1,1), TGARCH (1,1), and the implementation of numerous variance ratio models to test the random walk hypothesis under the EMH, which is discussed in detail in the Data and Methodology Chapter 3.

Chapter 3

Data and Methodology

3.1 Introduction

This chapter presents a description of the data and methodologies that were selected based on the reviewed literature. This helped with the selection of appropriate econometric models that were applied in the three research papers that present the core research outcomes of this thesis. The literature helped to identify a methodological framework to analyse crude oil spot and futures prices under three core themes. It provided econometric tools to answer the outlined research questions and to ensure that the research outcomes were robust.

The methodologies used in Chapters 4 to 6 are described in more detail in the Methodologies subsection in this chapter. The structure of this chapter is as follows: firstly, it offers a description of the research questions and objectives; secondly, it defines the dataset that was used to support this thesis; thirdly, it presents an overview of the econometric models chosen to analyse the data with detailed discussions on the relevance and suitability of each model to support the analysis of the issue under consideration.

3.2 Research Questions

The research questions of this thesis, as stated in Chapter 1 are as follows:

Question 1: Is there a long and/or short run (cointegration and causality) relationship between crude oil spot and futures prices?

Question 2: Is volatility of crude oil spot and/or futures prices higher during periods of crises?

Question 3: Are crude oil spot and/or futures prices efficient in the long, medium and short run?

The reviewed literature identified econometric models to answer the first research question to establish the long and short run relationship between crude oil spot and futures prices. The Johansen (1988) cointegration test was applied by Bekiros and Diks (2008) and Narayan et al. (2010) in their study of spot and futures oil prices, and the Engle-Granger (1987) cointegration test was also used by Bekiros and Diks (2008) and Westgaard et al. (2011). Both tests are implemented to examine the long run relationship between spot and futures prices. They are followed by causality testing, which has the ability to establish the short run relationship between variables. For example, Silvapulle and Moosa (1999) and Candelon et al. (2013) tested causality with the help of the Granger (1969) causality test and the Vector Error Correction Model (VECM), which is implemented in cases of cointegration to establish the short run relationship. The GARCH type models help to forecast the volatility of financial data as applied by Salisu and Fasanya (2013), Charles and Darné (2014), Zhang et al. (2015) and Zhang and Li (2016). The econometric models used in efficiency analysis, to answer the third research question, are the variance ratio tests proposed by Lo and MacKinlay (1988 and 1989) followed by the Wright (2000) variance ratio test, wild bootstrapping by Kim (2006) and the more recent Monte Carlo simulations by Charles et al. (2011). The efficiency methods were applied by researchers such as Hoque et al. (2007) and Charles and Darné (2009 and 2011).

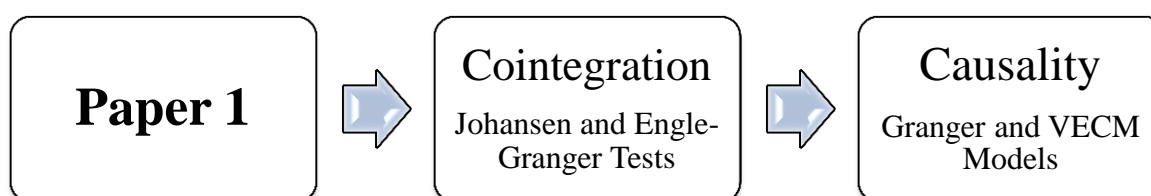
3.3 Research Objectives

The understanding of the lead-lag relationship between crude oil spot and futures prices during major crises and related stable periods before and after each crisis provides valuable advantage to oil market participants, investors and policy makers of both markets behaviour. It provides an important tool during times of major distress, mainly through investment and hedging activities as the knowledge gained from cointegration, causality, volatility and efficiency analysis offers many insights on crude oil markets behaviour through risk management strategies during crises. It especially indicates how the strategies should be adjusted depending on the type of crisis (supply/demand or economic/financial).

3.3.1 Long Run and Short Run Relationship

The objective of the long run and short run relationship is to establish the lead-lag dynamics between crude oil spot and futures prices. Identification of the leading price during crises can be used for decision making and portfolio selection and to help long term and short term investment plans. Figure 3.1 highlights the key methodologies applied in Paper 1 of Chapter 4.

Figure 3.1: Main Models for Paper 1

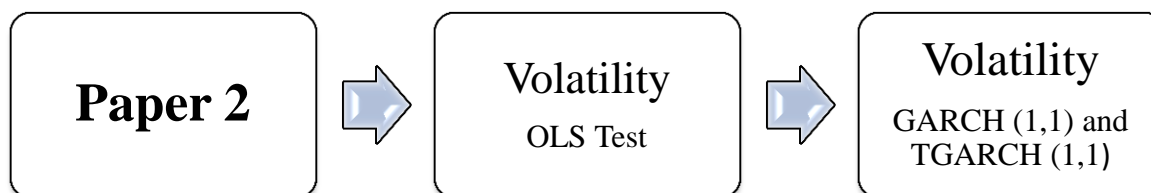


Source: The author (2018)

3.3.2 Volatility

The objective of volatility analysis for oil spot and futures prices during various crises can detect different volatility behaviours depending on the crisis' triggers. The selection of supply and demand shocks compared to economic and financial crises offers comparative analysis between the types of shocks for both oil markets, which can indicate when and for how long to hedge against the rising oil price risk. It can also suggest the effects of oil price returns in future periods. Figure 3.2 identifies the main volatility models.

Figure 3.2: Main Models for Paper 2

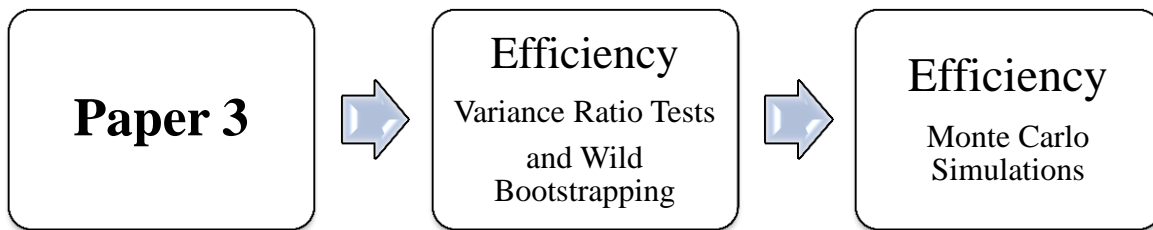


Source: The author (2018)

3.3.3 Efficiency

The main objective for efficiency examination is to observe if crude oil prices follow a random walk hypothesis. In this way, it can be learnt if future oil prices can be predicted based on past price behaviour, which can help to forecast the future oil price trend and assist with decision making processes. Figure 3.3 represents the methodologies applied in Paper 3 of Chapter 6.

Figure 3.3: Main Models for Paper 3



Source: The author (2018)

3.4 Data

This section outlines the dataset used in the research papers to examine the lead-lag relationship between crude oil prices. It includes daily closing spot prices and continuous futures prices, which were downloaded from the Thomson Reuters DataStream. The dataset details are shown in Table 3.1. The dataset in the first and second research paper includes Brent crude oil daily prices from 7 December 1988 until 31 December 2013 to analyse the long run and short run relationship between spot and futures markets, and volatility spikes and persistence. The third research paper analyses the efficiency of Brent, WTI and Dubai crude oil markets. The time period starts on 29 January 1986, which is a joint date for Brent, WTI and Dubai spot prices. The end of the test period is 5 September 2016 so as to offer sufficient data for a stable period after the global financial crisis. The data set consists of daily closing spot and daily continuous futures prices for Brent, WTI and the Dubai crude oil markets. All crude oil prices are in US Dollars per barrel.

Table 3.1: Dataset Details

	Data	Variable	Frequency	Time Period
PAPER 1	Spot and Futures prices	Brent	Daily	7 December 1988 to 31 December 2013
PAPER 2	Spot and Futures prices	Brent	Daily	7 December 1988 to 31 December 2013
PAPER 3	Spot and Futures prices	Brent, WTI, Dubai	Daily	29 January 1986 to 5 September 2016

Source: The author (2018)

The data samples were carefully chosen to include major crises in the oil markets as the main point of the analysis. It also includes periods of relative stability before and after the major crises, which gives strength to this research as this research offers a comparative analysis between major shocks in the oil markets and stable periods around the shock events.

3.5 Methodologies

This section starts with a description of applied econometric models and continues with a discussion of the relevant literature research, which helped with the selection of econometric methods used in this thesis. It offers initial methodologies required in time series analysis to ensure robustness of the data so as to avoid spurious results. Firstly, it outlines stationarity and structural break analysis. Then it provides key information and the methodologies applied in this thesis including cointegration, causality, volatility and efficiency testing. These methods highlight the main dynamics and signals in crude oil markets and their connections to, implications for and impact on businesses during crises periods. In this regard, oil price forecasts are of a great value to many industries, such as transport, airline or chemical sectors.

3.5.1 Initial Analysis

This initial analysis of oil spot and futures prices starts with the basic mean equations.

Therefore, the mean equations are outlined below:

$$S_{yt} = \beta_0 + \beta_1 * S_{it} + \beta_2 * S_{it-1} + \dots + \beta_n * S_{it-n} + \varepsilon_t \quad (3.1)$$

$$S_{it} = \beta_0 + \beta_1 * S_{yt} + \beta_2 * S_{yt-1} + \dots + \beta_n * S_{yt-n} + \varepsilon_t \quad (3.2)$$

Where S_{yt} refers to oil spot price of variable y ; S_{it} is oil spot price of variable i ; ε denotes the error term; and t is time series daily data.

3.5.2 Stationarity and Structural Breaks

The stationarity of time series data is the first test conducted in the analysis. This test establishes if the dataset has a unit root, which tests if it is a non-stationary process. In other words, stationarity means that the time series moves around its mean value. Non-stationary data cannot be used in econometric testing as the results of tests cannot be relied on. A widely used stationarity test (Zivot and Andrews, 1992; Sadowsky, 1999; Bekiros and Diks, 2008; Robe and Wallen, 2016) is the Augmented Dickey-Fuller test (Dickey and Fuller, 1979). The formula for the random walk form is presented below.

$$\Delta y_t = \phi y_{t-1} + \varepsilon_t \quad (3.3)$$

As stationarity is important for the stability of models in time series data, which provide a framework that can be used in describing data series behaviour, the relevant research technique was applied. The Augmented Dickey-Fuller (ADF) test by Dickey and Fuller (1979), established that oil prices are stationary in returns (Bekiros and Diks, 2008; Zhang and Wang, 2013; Ding et al., 2014) and therefore the majority of the reviewed research studies use the natural log in their analysis. In accordance with the literature findings, this thesis starts its analysis with the assessment of stationarity properties. In this study multiple econometric models are used to analyse spot and futures prices with specific attention to shocks in the oil market connected with structural breaks corresponding to various shocks in the oil markets.

To identify structural break points, a variety of models can be used. Structural break points are unexpected shifts in oil price behavior that need to be included in analysis to avoid spurious results. To identify the existence of such breakpoints, typical tests include the Chow test, the Quandt-Andrews test and the Bai-Perron test. These tests were selected based on the existing literature (Hansen, 2001; Bekiros and Diks, 2008; Mensi et al., 2014) and have been found to work well when studying commodity markets. The main differences between the tests are that the Chow and Quandt tests can identify only a single break point. In the case of Chow test, we look at a specific date and a break point is either found or not recognised. The Quandt test can find a break point from the series. The Bai-Perron test has the ability to find multiple breaks in the data set. This identifies structural changes in the time series which then can be connected to specific events. Structural breaks can help businesses with strategies and planning by identifying dynamics and patterns in certain periods.

To identify the particular break points for the series, typically the Chow test (Chow, 1960) is first applied. It consists of breaking the sample into two or more structures, on a specific date, and its equation is:

$$F = \frac{(SSR_n - (SSR_{n_1} + SSR_{n_2}))/k}{(SSR_{n_1} + SSR_{n_2})/(n_1 + n_2 + 2k)} \quad (3.4)$$

where SSR_n is the combined regression line, SSR_{n_1} is the regression line before the break and SSR_{n_2} is the regression line after the break.

The Quandt-Andrews test is an extension to the Chow test and it is used in situations where the break-date is unknown (Hansen, 2001). Quandt (1960) proposed taking the largest Chow statistic over all possible break-dates which essentially is the likelihood test under normality. On the other hand, the Bai-Perron test is capable of identifying multiple structural breaks. This test examines the break points between multiple variables simultaneously. The recommended number of break points is five as more breaks could lead towards problems in terms of testing, as they will condition the number of observations available for study (Mensi et al., 2014). Bai and Perron's (1998) main framework of analysis can be described by the following multiple linear regression with m breaks (or $m+1$ regimes):

$$y_t = x_t' \beta + z_t' \delta_j + \mu_t ; \quad t = T_{j-1} + 1, \dots, T_j \quad (3.5)$$

for $j = 1, \dots, m+1$. In this model, y_t is the observed dependent variable at time t ; both for x_t ($p \times 1$) and z_t ($q \times 1$) are vectors of covariates and β and δ_j ($j = 1, \dots, m + 1$) are the corresponding vectors of coefficients; μ_t is the disturbance at time t . Break points are explicitly treated as unknown; $T_0 = 0$ and $T_{m+1} = T$ is used. The objective is to estimate the unknown regression coefficients together with the break points when T observations on y_t, x_t, z_t are available. This is a partial change model since

the parameter vector β is not subject to shifts and is estimated using the entire sample (Bai and Perron, 2003). A combination of tests is used to ensure that the changes in the data series are robust to the implementation of different methods. While further methodologies exist, the outcomes of the three tests explained here are usually quite consistent, thus obviating the need for further testing in this regard.

Structural break tests are used to identify structural changes in time series, which could have a negative impact on econometric outcomes. In this way, the discovery of shocks or crises is possible. The crises periods in this thesis were identified by the Chow test (Chow, 1960), the Quandt-Andrews test (Quandt, 1960) with unknown break dates and the more sophisticated Bai-Perron test (1998) used by researchers such as Hansen (2001), Bekiros and Diks (2008), and Mensi et al. (2014). The combination of structural break tests helped to ensure the robustness of the break dates. The Bai-Perron test's outcomes were taken for further analysis as it can detect multiple break points over a long-time period. This test was applied to spot and futures daily returns and helped with the further investigation of oil markets and their behaviour in certain points in turbulent times. The combination of the tests confirmed the structural breaks of the series and as a result there was no necessity to include further break point analysis.

3.5.3 Cointegration

Cointegration techniques are used to investigate the presence of a long term relationship between variables. This means that if there is more than one variable, there are tests available to examine if they influence each other, and to identify which of those variables may be leading the other variables. This can be used in recognizing a leading price, which would set a trend for the lagging price. This can simplify the decision-making process when having multiple stocks or shares in a

portfolio which has the long term relationship integrated into the portfolio. The selected research methodology offers insight into the kind of relationship that characterizes oil prices by comparing the outcomes. In the case of this thesis, spot and future prices can be tested to see if they share a long term relationship. The Johansen cointegration test (Johansen, 1988) can be applied in combination with the Engle and Granger (1987) approach, thus permitting cross checking of the results and identifying if the outcomes from both tests are consistent. This reliance on more than one test gives more certainty to the outcomes. The Johansen (1988) approach extends the single equation error correction model to a multivariate one. Let's assume that there are three endogenous variables y_t , x_t and w_t and the matrix notation is $Z_t = [y_t, x_t, w_t]$

$$Z_t = A_1 Z_{t-1} + A_2 Z_{t-2} + \dots + A_k Z_{t-k} + \mu_t \quad (3.6)$$

The above equation is equivalent to the single equation dynamic model for two variables y_t and x_t . It can be reformulated in a vector error correction model (VECM) as:

$$\Delta Z_t = \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \dots + \Gamma_{k-1} \Delta Z_{t-k+1} + \Pi Z_{t-1} + \mu_t \quad (3.7)$$

where $\Gamma_i = (I - A_1 - A_2 - \dots - A_k)$ ($i = 1, 2, \dots, k-1$) and $\Pi = -(I - A_1 - A_2 - \dots - A_k)$.

The VECM model includes the Error Correction Term (ECM) that corrects causality analysis in cases of cointegration. The cointegration examination of the long term relationship between spot and futures returns offer insight on behavioural characteristics for planning purposes. The most common approaches in oil markets are the Johansen cointegration test (Johansen, 1988) and the Engle-Granger cointegration model (Engle and Granger, 1987). For example, Narayan et al. (2010) studied the long term relationship between oil and gold futures markets and applied both tests in their

analysis. Similarly, Mitra (2018) applied the Johansen cointegration test to analyse the long run relationship between oil price and stock returns. Alternative methodologies are available such as Quantile Cointegration developed by Xiao (2009) and applied by Lee and Zeng (2011) to test crude oil spot and futures prices for different futures contracts maturities; however this thesis is supported by well-known and established econometric cointegration models as they offer robust results for spot and futures prices modelling.

3.5.4 Causality

Causality testing is about understanding short term relationships. The specific research method under consideration was chosen based on the reviewed literature (Bekiros and Diks, 2008; Wang and Wu, 2013; Ding et al. 2014; Mehrara and Hamldar, 2014). Causality modelling is used to identify short term relationships and their direction of influence by looking at short run movements on a continuous basis. This is of interest when looking at oil price dynamics during different periods as it can offer insight for businesses during various economic, political or business cycles. The well-established Granger Causality test (Granger, 1969) was implemented, where two stationary variables are regressed against each other in two separate equations.

$$y_t = \alpha_1 + \sum_{i=1}^n \beta_i x_{t-i} + \sum_{j=1}^m \gamma_j y_{t-j} + \varepsilon_{1t} \quad (3.8)$$

$$x_t = \alpha_2 + \sum_{i=1}^n \theta_i x_{t-i} + \sum_{j=1}^m \delta_j y_{t-j} + \varepsilon_{2t} \quad (3.9)$$

where y_t is a dependent variable and x_t is an independent variable regressed against y_t .

In the case of Brent Crude oil spot and futures prices, Zhang and Wang (2013) identified that at some points in time spot prices cause futures prices. The presented research methodology was carefully selected to ensure that the long and short run relationship between the series under study were properly analyzed and consistent with econometric techniques available and commonly used by researchers in the field and that aligned with the extant literature (Bekiros and Diks, 2008; Lee and Zeng, 2011; Mamatzakis and Remoundos, 2011; Candelon et al., 2013; Wang and Wu, 2013; Ding et al., 2014; Batten et al., 2017). Where the variables are found to be cointegrated then the VECM model presented in equation (3.7) is applied. This model includes the Error Correction term (ECM), which corrects the Granger causality test in the presence of long run relationships; otherwise the model would be mis-specified. Mitra (2018) also applied the Granger causality test (Granger, 1969) for short term testing. A causality analysis of oil markets was investigated by Bekiros and Diks (2008) who applied the Granger causality test and VECM model to crude oil markets. Other researchers using the above models in their analysis are, for example, Silvapulle and Moosa (1999) and Candelon et al. (2013). For this reason, cointegration and causality tests, which work well for oil markets data, are applied in this research to gather information on spot and futures oil returns behaviour when analysing stable and turbulent time periods over long and short term periods.

The combination of the chosen methodologies bring value to practitioners and academics in understanding the relationship between oil prices in different periods as the findings could point towards interesting outcomes in terms of a lead-lag relationship between oil prices, especially when the series are affected by shocks or in the presence of structural breaks.

3.5.5 Volatility Models

Volatility forecasts are used to predict price returns and identify significant changes in oil price behaviour. The GARCH type models are applied in this analysis as they offer the most successful outcomes for volatility modelling for financial data (Mensi et al., 2013; Chkili et al., 2014; Shabani et al., 2017). This is an important issue for businesses, investors and speculators as it could suggest and help to forecast future trends. The well-known Generalised Autoregressive Conditional Heteroskedasticity (GARCH) model presented by Bollerslev (1986) is used in this study. This method is preferred by financial modelling professionals for its simplicity in volatility modelling. The Threshold GARCH (T-GARCH) model by Zakoian (1994) is also included as it can capture asymmetries. Firstly, the ARCH model presented by Engle (1982) suggests that the variance of the residuals at time t depends on the squared error term from past periods. The ARCH (q) model specification is presented in equations (3.10) and (3.11) below:

$$y_t = \alpha + \beta'x_t + \varepsilon_t \quad (3.10)$$

where, $\varepsilon_t | \Omega_t \sim iid N(0, h_t)$,

and

$$h_t = \gamma_0 + \sum_{j=1}^q \gamma_j \varepsilon_{t-j}^2 \quad (3.11)$$

The generalised ARCH model by Bollerslev (1986) known as GARCH (p, q) is outlined as follows:

$$y_t = \alpha + \beta'x_t + \varepsilon_t \quad (3.12)$$

where, $\varepsilon_t | \Omega_t \sim iid N(0, h_t)$,

and

$$h_t = \omega + \sum_{i=1}^p \alpha_i h_{t-i} + \sum_{j=1}^q \gamma_j \varepsilon_{t-j}^2 \quad (3.13)$$

Equation (3.13) states that the value of the variance scaling parameter now depends both on past values of the shocks, which are captured by the lagged squared residual terms, and on the past values of itself, which are captured by lagged terms. The simplest form of GARCH (p, q) model is the GARCH (1, 1), which is commonly used by many researchers in oil markets, as it generally performs better than higher order GARCH models (Lee et al., 2006; Narayan and Narayan, 2007; Salisu and Fasanya, 2013), for which the variance equation is:

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} \quad (3.14)$$

The ARCH and the GARCH models are symmetric; however, it has been observed that negative shocks have greater impact on volatility than positive shocks in most financial time series such as stocks and commodities. Therefore, to test for asymmetries in the conditional variance the T-GARCH model is considered appropriate and therefore it is included as part of this study. The specification of the conditional variance equation for T-GARCH (1,1) is given by:

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \theta \varepsilon_{t-1}^2 d_{t-1} + \beta h_{t-1} \quad (3.15)$$

where, d_t takes the value of 1 for $\varepsilon_t < 0$, and 0 otherwise. This means that positive and negative shocks have different impacts. Positive news has an impact of α , whereas negative shocks have an impact of $\alpha + \theta$.

The well-known Generalised Autoregressive Conditional Heteroskedasticity (GARCH) model, presented by Bollerslev (1986), attracts academics, researchers and financial modelling professionals by its simple use. The GARCH modelling is widely used for volatility analysis in financial markets

and also in crude oil commodity markets. This method still shows its strengths nowadays by being implemented in the vast majority of volatility studies. One of the first papers considering crude oil volatility was Antoniou and Foster (1992). They examined oil volatility with the help of the GARCH model. Similarly, Charles and Darné (2014) examined volatility persistence for Brent, WTI and OPEC's crudes using GARCH type models. They also implemented structural breaks to improve the analysis. Volatility analysis with structural breaks was also conducted by Salisu and Fasanya (2013). The implementation of GARCH models (GARCH (1,1), GARCH-in mean, EGARCH and TGARCH) exhibited high level of volatility persistence with variations over time. Moreover, it showed indications of negative shocks having higher impact on volatility than positive news. The GARCH type methodologies were also applied by Zhang and Wang (2013), Zhang et al. (2015) and Zhang and Li (2016) as it has the ability to identify volatility behaviour of crude oil data. As a result, the analysis of the crude oil market during shock periods is needed to help with decision making practices in future strategic planning as it could offer necessary information for oil market investors. Also, Wang and Wu (2012) using GARCH models, researched the volatility of crude oil markets and pointed out that oil markets are very volatile during shocks and oil price jumps, which are primarily driven by supply and demand changes. As this study considers simple volatility analysis to capture its magnitude during unstable periods, the basic OLS volatility and GARCH (1,1) models are applied and also the TGARCH (1,1) model as it has the ability to identify volatility asymmetries.

The volatility outcomes from the GARCH and TGARCH models show the spikes, persistence and asymmetries of oil price returns and capture the differences when applied to different sub-periods. The T-GARCH model was included due to the analysis' focus on crises periods, where the T-GARCH model has the ability to identify if there is evidence of significant differences on volatility behaviour during times of sustained uncertainty, such as the ones associated with crises events that would generally be considered as negative news.

3.5.6 Efficiency Models

The methods for analysing market efficiency are typically based on the Efficient Market Hypothesis theory (Fama, 1965), where the main idea of this concept is based on the Random Walk hypothesis, which is considered as the weak form of EMH. It states that future prices should not be predicted by past price behaviour. Based on this theory, the Variance Ratio (VR) tests are widely used for efficiency testing (Liu and He, 1991; Hoque et al., 2007; Charles and Darné, 2009). Firstly, the conventional Lo and MacKinlay (1988) VR test is explained, and then the application of the Chow-Denning (1993), Wright (2000) and the more recent wild bootstrapping by Kim (2006) are discussed. Also, details of wild bootstrapping using GARCH residuals models are discussed as they represent a further advance on the methods. The importance of oil market efficiency offers interesting insights to oil market practitioners by looking at the predictability or the randomness of oil prices. Moreover, it indicates if the tested variables can be predicted over time or if they are exhibiting random patterns. This can be used for strategic and investment decisions by oil dependent businesses and industries.

3.5.6.1 Variance Ratio Tests

3.5.6.1.1 Lo and MacKinlay (1988 and 1989)

Lo and MacKinlay (1988; 1989) first introduced the VR test for efficiency testing. They proposed a test statistic under homoscedasticity¹² and also under heteroskedasticity¹³. Oil price data, the focus of this thesis, typically show evidence of heteroskedasticity which was confirmed. Therefore, we perform the test under the heteroskedasticity. In other words, it means that the variability of a

¹² Homoscedasticity is an assumption that the variance around a regression line is the same for all values of predictor variable (the variance of the errors should be constant).

¹³ Heteroscedasticity is present when the size of the error term differs across values of an independent variable (the dataset is not homoscedastic).

variable is unequal across the range of values of a second variable that predicts it and we have to take that into account when modelling our data.

Firstly, we specify our regression by P_t being the spot price of Brent, WTI or Dubai crude oil daily price at the time t and define $X_t = \ln P_t$ as the log price process. The regression is as follows:

$$X_t = \mu + X_{t-1} + \varepsilon_t \quad (3.16)$$

where μ is the arbitrary drift parameter and ε_t is the random disturbance term. Since financial data exhibit changing volatilities over time the specification test of the random walk model must be robust to changing variances. If the oil price follows a random walk or martingale then the price return is unpredictable from the past price information. Following Wright (2000), the VR test can be written as:

$$VR(x; k) = \left\{ \frac{1}{Tk} \sum_{t=k}^T (x_t + x_{t-1} + \dots + x_{t-k+1} - k\hat{\mu})^2 \right\} \div \left\{ \frac{1}{T} \sum_{t=1}^T (x_t - \hat{\mu})^2 \right\} \quad (3.17)$$

where $\hat{\mu} = \frac{1}{T} \sum_{t=1}^T x_t$. This is an estimator for the unknown population VR, denoted as $V(k)$, which is the ratio of $1/k$ times the variance of the k -period returns to the variance of the one-period return. Lo and MacKinlay (1988) showed that if x_t is independent and identically distributed (iid), then under the null hypothesis that $V(k) = 1$,

$$M_1(x; k) = (VR(x; k) - 1) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \quad (3.18)$$

follows the standard normal distribution asymptotically. To allow for x_t 's showing conditional heteroskedasticity, Lo and MacKinlay (1988) proposed a test statistic that is robust for heteroskedasticity,

$$M_2(x; k) = (VR(x; k) - 1)(\sum_{j=1}^{k-1} [\frac{2(2k-j)}{k}]^2 \delta_j)^{-1/2} \quad (3.19)$$

which follows the standard normal distribution asymptotically under null hypothesis that $V(k) = 1$, where,

$$\delta_j = \{\sum_{t=j+1}^T (x_t - \hat{\mu})^2 (x_{t-j} - \hat{\mu})^2\} \div \{[\sum_{t=1}^T (x_t - \hat{\mu})^2]^2\} \quad (3.20)$$

This original variance ratio test is robust under the existence of heteroscedasticity and therefore is ideal for crude oil prices. It is a model which can offer strong results in terms of oil market efficiency and its predictability for oil market practitioners.

3.5.6.1.2 Chow-Denning (1993)

In comparison to the Lo and MacKinlay (1988) test, which is an individual test where the null hypothesis is tested for an individual value of k , there is a question if stock returns are mean-reverting, which will require the null hypothesis to hold for all values of k . Therefore, it is necessary to conduct a joint test, where a multiple comparison of VRs over a set of different time horizons is made. Under the null hypothesis, $V(k_i) = 1$ for $i = 1, \dots, l$ against the alternative hypothesis that $V(k_i) \neq 1$ for some i . Their test statistic is as follows:

$$MV_1 = \sqrt{T} \max_{1 \leq i \leq l} |M_1(x; k_1)| \quad (3.21)$$

where $M_1(x; k)$ is defined in equation (3.18). The idea is that the decision regarding the null hypothesis can be based on the maximum absolute value of the individual VR statistics. The null hypothesis is rejected at α level of significance if the MV_1 statistics is greater than the $[1-(\alpha^*/2)]$ th percentile of the standard distribution, where $\alpha^*=1-(1-\alpha)^{1/l}$. The heteroskedasticity-robust version of this test can be written as:

$$MV_2 = \sqrt{T} \max_{1 \leq i \leq l} |M_2(x; k_i)|, \quad (3.22)$$

which is a joint test using $M_2(x; k)$ given in (3.19).

This multiple variance ratio test allows for multiple comparisons, which can be used to compare the outcomes with the original Lo and MacKinlay (1988) VR test.

3.5.6.1.3 Wright (2000)

The standard VR test is based on asymptotic approximations, which may be biased and right-skewed in finite samples, which can result in misleading inferences (Lo and MacKinlay, 1989). Wright (2000) proposes to modify the standard VR test using standardised ranks and signs. This has two advantages. Firstly, as the sign and rank tests have exact sampling distribution, there is no need to resort to asymptotic approximation. Secondly, the tests may be more powerful than the conventional VR tests when the data is highly non-normal (Wright 2000).

The proposed statistics are as follows:

Let $r(x_t)$ be the rank of x_t among x_t 's and consider the standardised rank $r_{1t} = [r(x_t) - 0.5(T+1)]/[(T-1)(T+1)/12]$. Under the null hypothesis that x_t is generated from an iid sequence, $r(x_t)$ is a random permutation of the numbers of $1, \dots, T$ with equal probability.

$$R_1 = \left(\frac{(Tk)^{-1} \sum_{t=k}^T (r_{1t} + r_{1t-1} + \dots + r_{1t-k+1})^2}{T^{-1} \sum_{t=1}^T r_{1t}^2} \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \quad (3.23)$$

$$R_2 = \left(\frac{(Tk)^{-1} \sum_{t=k}^T (r_{2t} + r_{2t-1} + \dots + r_{2t-k+1})^2}{T^{-1} \sum_{t=1}^T r_{2t}^2} \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \quad (3.24)$$

which follows an exact sampling distribution.

The modification of the traditional VR test using the ranks and signs can minimise size distortions and it is a good efficiency test to be included in the analysis for comparative reasons.

3.5.6.1.4 Kim (2006)

Kim (2006) offers a wild bootstrap approach to improve small sample properties of variance ratio tests with unknown forms of conditional and unconditional heteroskedasticity. The approach involves computing the individual Lo and MacKinlay $M_2(k)$ and joint Chow-Denning $MV_2(k_i)$ VR tests on samples of T observations formed by weighting the original data with random variables with mean of 0 and variance of 1. The results are used to form bootstrap distributions of the test statistics.

The wild bootstrap test based on $MV_2(k_i)$ can be computed in three stages as follows:

- 1) Form a bootstrap sample of T observations $X_t^* = \eta_t X_t (t = 1, \dots, T)$ where η_t is a random sequence with $E(\eta) = 0$ and $E(\eta^2) = 1$.

- 2) Calculate $MV^* = MV_2(X^*; k_i)$ statistic obtained from the bootstrap sample generated in stage 1).
- 3) Repeat 1) and 2) sufficiently, say m , times to form a bootstrap distribution of the test statistic $\{MV_2(X^*; k_i; j)\}_{j=1}^m$.

The p -value of the test can be obtained as the proportion of $\{MV_2(X^*; k_i; j)\}_{j=1}^m$ greater than the sample value of $MV_2(k_i)$. The wild bootstrap version of $M_2(k)$ test can be implemented in a similar way as a two-tailed test, where we obtain $M^* = M_2(X^*; k)$ in stage 2) and $\{MV_2(X^*; k_i; j)\}_{j=1}^m$ in stage 3). Conditionally on X_t , X_t^* is a serially uncorrelated sequence with zero mean and variance X_t^2 . M^* and MV^* have the same asymptotic distributions as $M_2(k)$ and $MV_2(k_i)$ respectively. Since X_t^* is a serially uncorrelated sequence, wild bootstrapping approximates the sampling distributions under the null hypothesis, which is a necessary property for a bootstrap test. Kim (2006) recommends using the standard normal distribution as other choices provide similar results. The wild bootstrapping approach is another model in efficiency testing, where a resampling method approximates the sampling distribution of a test statistics.

3.5.6.2 Monte Carlo Simulations

Charles et al. (2011) used Monte Carlo simulations to test for market efficiency based on GARCH residuals. They considered the models outlined below to support their research study.

- AR(1) model: $Y_t = 0.1Y_{t-1} + Z_t$, and $Y_t = 0.1Y_{t-1} + V_t$
- ARFIMA model: $(1 - L)^{0.1}Y_t = Z_t$, and $(1 - L)^{0.1}Y_t = V_t$
- The sum of a white noise and the first difference of a stationary autoregressive process of order one (NDAR): $Y_t = \varepsilon_t + X_t - X_{t-1}$ with $X_t = 0.85X_{t-1} + \mu_t$

where $Z_t = \varepsilon_t \mu_t$ with $\sigma_t^2 = 0.001 + 0.90\sigma_{t-1}^2 + 0.09\varepsilon_{t-1}^2$ (i.e. GARCH(1,1) errors);

$V_t = \exp(0.5h_t) \varepsilon_t$ with $h_t = 0.95h_{t-1} + \mu_t$ (i.e. stochastic volatility (SV) errors); ε_t and μ_t are independent i.i.d $N(0,1)$. This model uses GARCH (1,1) residuals in the wild bootstrapping method proposed by Kim (2006) in the previous section, which offers more precise results when testing oil prices.

Efficiency analysis is of a great interest to oil market investors and policy makers. It is important to know the efficiency of oil prices from a long term and short term view as the implications for decision making and strategic planning could offer vital information for all interested parties, such as arbitrage opportunities during different time periods in spot and/or futures oil markets. For this reason, numerous efficiency models are included in this thesis to recognise the random walk hypothesis of crude oil prices for times of tranquillity and turbulence.

The key methods presented in this chapter are applied in the empirical part of the three research papers. This offers a practical view on how the outlined tests can be used by researchers and practitioners to understand the dynamics of oil markets and how the analysis of oil prices behaviour can help in the decision making process.

3.6 Conclusion

There are a significant number of business participants who could benefit from studies which analyse commodities from different methodological perspectives, as each research paper offers detailed analysis and different insights for periods of distress. The combination of multiple methodologies under different scenarios characterised by substantial levels of market uncertainty brings more light and robustness to crude oil prices examination. This brings value to businesses and industries, which depend on oil, as it has the ability to look at price performance from different angles. Each method

has its strengths and when combined it offers rich insight, having its purpose and place in business research. The comparative advantage of established and more recent methods gives the opportunity to analyse the outcomes of each test. This can provide better understanding of the results depending on the time frame and nature of individual testing variables in specific time periods. The methodologies in the three research papers provide great value for portfolio management and decision-making practices by enriching the decision-making process.

Additionally, the advantage of the three research papers' brings together methodological approaches, which determine the behaviour of oil prices during crises periods and high oil price fluctuations. Moreover, different theories and models support strategic planning and help to understand the behaviour and performance of oil prices for oil dependent industries, investors, speculators and other oil market participants. In turbulent times, uncertainty and business risk grow and companies have to pay more attention to business tactics and hedging. Good decision making can vastly reduce risk and save money based on good planning, which can be done with the help of focused research studies. Therefore, there are many market participants who could benefit from the research outcomes and prevent the damage and high costs that are associated with business environments that are affected by risk and uncertainty.

The combination of multiple approaches enhances the robustness of the research findings and explains why variables move in a certain way by capturing their behaviour. It also brings confidence in the obtained results as it can integrate multiple theories. Due to a vast number of research methodologies the multiple models applied in each area of study (long and short run relationships between oil spot and futures prices, volatility analysis and price efficiency) support or add to each models' outcomes to increase or confirm the results. Other robustness checks were conducted in the case of volatility analysis, where the suitability of GARCH models was tested by checking the

ARCH effects through the ARCH-LM test and serial correlation with the help of correlogram Q-statistics and correlation squared residuals. Furthermore, in all the analysis, the lag length selection was carefully conducted for all tested variables as the results could be affected by applying different lag lengths criteria.

Investors' needs in decision making processes rely on their ability to understand oil prices performance and historical trends. In this way they can lower the risk and uncertainty, which could have a negative impact on their business. Furthermore, if businesses compare outcomes from various models using specialised research, it gives them more confidence in their strategies when connecting the outcomes in the business field. This can be a key tool, which could help oil dependent industries such as transportation, airlines or the chemical sector with decision making practices during crises periods.

Chapter 4 - Paper 1

Brent Crude Oil Spot and Futures Prices Dynamics during Times of Crises¹⁴

4.1 Abstract

The relationship between oil spot and futures prices is complex. Using structural break, cointegration, and causality analysis, Brent crude spot and futures prices are examined before, during and after two specific crises permitting the study of the impact of two major shocks on their relationship. A long run bidirectional relationship between spot and futures prices was found during the analyzed crises periods. The core research outcomes indicate that different types of crises engender different levels of causal relationships between Brent crude spot and futures prices.

Keywords: crude oil; spot prices; futures prices; cointegration; causality; crises

JEL codes: G01, G10, Q40

4.2 Introduction

Oil is identified as the most actively traded commodity on a global scale that has been powering the world economy for many decades (Robe and Wallen, 2016). Crude oil is used as a raw material for the production of many goods and in its refined forms is utilized across many industries. Therefore, an in depth understanding of oil price behavior, price formation and their associated dynamics is

¹⁴ This paper has been reformatted to fit with the DIT thesis presentation guidelines.

essential to aid governments, private investors and organizations in their planning and investment strategies. The dynamics of oil prices and subsequent implications for economic growth and development is a matter of significant importance due to the fact that at present there are no viable alternatives to this energy resource that offer similar performance and cost attributes, justifying the need for research studies that shed light on how oil prices behave and perform. The price of oil has experienced significant changes over time due to factors such as wars, political change, unrest in oil producing and oil consuming countries and business cycles. For example, in the case of the first Gulf War, oil price fluctuations were caused by the political tactics of Iraq, a situation which led to major oil supply disruption. Meanwhile, during the global financial crisis price fluctuations were predominantly caused by inefficiencies in financial markets that led to the bursting of the US property bubble that transmitted further uncertainty to oil market demand. This variability was shown through a rapid increase followed by a sudden drop in oil prices, principally caused by a considerable decline in oil needs by the construction and transport sectors, concluding in significant increases in price volatility (Liu et al., 2015).

This paper makes a valuable contribution to the field of study, as it considers the relationship between spot and future prices of crude oil, as oil prices seriously affect macroeconomic growth, and times of market uncertainty need to be closely examined. In the context of this study, supply and demand side shocks are considered of interest as they are associated with different market dynamics (Sari et al., 2010; Cunado et al., 2015). “In theory, since both spot and futures prices reflect the same aggregate value of the underlying asset and considering that instantaneous arbitrage is possible, futures prices should neither lead nor lag the spot price” (Bekiros and Diks 2008 pp. 2675). Nevertheless, Bekiros and Diks (2008) found that futures prices seem to influence spot prices; however, spot prices do not have an effect on futures prices. Bekiros and Diks (2008) concentrate on two periods (pre-1999 and post-1999) and do not explicitly take periods pre-, post-, or more

specifically, the crisis period is not examined in depth. This paper specifically concentrates on analyzing the relationship between spot and futures prices during stable and crises periods with the aim of understanding if prices association is subject to changes, and if dynamic patterns could be identified in the long and short run. Furthermore, the study of spot and future prices connection during the Gulf War (1990s) and the global financial crisis (2008) bring a new dimension to the study, as the origins of both events is quite different and had different implications for the oil sector. These are aspects that need to be explored in the context of prices interlinkages as they can bring valuable information to relevant market players.

Huang et al. (2009) find evidence of causality only when specific conditions relating to the underlying spot and futures prices are met. Lee and Zeng (2011) using a quantile cointegration approach found mixed evidence of directionality but did not include structural breaks in their analysis. This study is supported by structural break analysis to help identify relevant subsamples that deal with periods of sustained market uncertainty, as those associated with the core crises events under study.

After finding a break point for the beginning of the global financial crisis, Zhang and Wang (2013) found significant bi-directional causality, which implies that spot and futures markets influence each other and are similarly important in the oil price discovery process. However, if the global financial crisis is considered as having a demand side effect on the oil markets, there is a need to understand different kind of dynamics depending on the source of the shock. Liu and Wan (2011) focus on asymmetries relating to exceedance correlations and noted that these correlations reduced significantly in times of crises. The current study explicitly concentrates on two major macroeconomic events as a way of considering how significant events can shape the relationship between spot and futures prices. The modeling approach to consider the periods before, during, and

after the shocks is pertinent for the study of price dynamics, as it allows the developing of a comparative analysis that differentiates between times of “normality” and times of significant market disruptions. In this way the paper is building upon Kawaller et al. (1988), who in a study of the S&P500 index spot and futures prices, found that spot and futures prices are both affected by history and that their lead-lag relationship may change dramatically as new information arrives.

In order to understand the impact of different forms of crises the first Gulf War of 1990/1991 and the global financial crisis of late 2000s are chosen as periods that had a major impact on oil price changes, with very evident jumps experienced by prices during these events. Furthermore, the specific characteristics of these shock periods add value to the literature examining crude oil by looking at a supply shock experienced during the Gulf War, while a global economic/demand shock took place during the GFC. The first period is directly associated with a crude oil supply disruption, whereas the second period represents a major shock to the financial markets that was heavily felt in terms of liquidity and that had indirect effects on oil prices due to crude oil demand issues. These two shock periods created massive historical disruption in the oil market and were the source of remarkable changes in oil prices in recent history, as per the available records. A deliberate choice was made to ensure that the selected events dealt with market shocks that were associated with the supply and demand side as the oil prices association can be impacted by the source of the shocks. These two events signal major price changes that need to be carefully assessed when understanding oil price dynamics, as one has direct implications on the production of oil and the other affected the sector in an indirect manner. The selected two sub-samples provide an opportunity to analyze in depth oil price behavior that differentiates between times of increased and severe uncertainty and times of relative tranquility at a macroeconomic level.

Brent Crude oil prices were selected as the benchmark for the crude oil industry in this paper. Liu et al. (2015) note that the two most common oil benchmarks are Brent, primarily representing the European market and West Texas Intermediate (WTI), mainly focused on the US market. While other benchmarks are increasing in importance they are considered significantly illiquid (Liu et al., 2015), and as a result were not considered for this study. The WTI has been used as a benchmark since the early 1980s and according to Elder et al. (2014) also from 2007 to 2012; however, Brent Crude oil ‘stole’ the WTI crown in 2010, and since then it has been considered as the leading benchmark (EIA, 2014). Additionally, Brent represents not only the Northwest European crude oil market, but it is also used as the benchmark for all West African, Mediterranean and some Southeast Asian crudes, which links Brent directly to the largest markets. The preference for Brent oil today is due to it being a better indicator of global oil prices, as it is portrayed as a benchmark for other oil grades. Moreover, Brent crude is distributed in more than 70 countries and in 2012 had the world’s largest crude oil futures contracts in terms of negotiated volume. The year 2012 also saw a doubling of its market share since 2008 (The Ice, 2013). Another aspect to take into account is that much of the extant research uses West Texas Intermediate (WTI) data (Bekiros and Diks, 2008; Lee and Zeng, 2011; Liu and Wan, 2011; Zhang and Wang, 2013; Ding et al., 2014; Chang and Lee, 2015) and their results are mixed in relation to this lead-lag relationship. These points led to the selection of Brent as the suitable benchmark to support this study. There is also no evidence of studies that seek to compare price reactions before, during and after crises periods in the context that is presented in this study.

4.2.1 Research Motivation and Contribution

Oil price changes are significantly influenced by economic growth and the behavior of oil spot and futures prices plays an important role for oil and non-oil market participants due to oil’s spillover

effects on the real economy (Hamilton 2014; Forni et al., 2015; Robe and Wallen, 2016). Thus, identifying oil price dynamics during times of economic distress adds value to the extant literature, as this area of research has not received sufficient attention (Sadorsky, 1999; Bekiros and Diks, 2008; Nicolau and Palomba, 2013; Mehrara and Hamldar, 2014; Balcilar et al., 2015). Research looking at oil prices behavior during times of financial distress aids in the design of appropriate policies to minimize the impact of negative shocks on countries' real economies. Thus, the research questions to be addressed in this paper consider oil price dynamics around times of turmoil in the markets: i) Are Brent Crude oil spot and futures prices dynamics subject to significant changes during times of crises?, and ii) Do oil prices behavior change during times of relative economic stability?

The outcomes of this paper show significant evidence of the existence of a long run bidirectional relationship between spot and future prices for the two crises periods. While, there was no relevant indication of causal relationships during the Gulf War Crisis period, a unidirectional short run relationship was identified for the global financial crisis period running from futures prices to spot prices. This was an interesting result given that a supply side shock such as the Gulf War would be expected to have a direct effect whereas a more general macroeconomic shock, like the global financial crisis, has a direct effect when an indirect effect would be expected. These macroeconomic shocks were instigated from different sources and seem to affect the relationship between spot and futures prices differently.

This paper makes several contributions to the extant body of knowledge. Firstly, through the use of structural break analysis to model the time series as a set of pre-crisis, crisis and post-crisis periods, a more nuanced view of the relationship between spot and futures prices is possible. Second, the explicit analysis of oil price dynamics during times of relative stability adds to the understanding of

price discovery in the market. Third, through consideration of different types of shock in the market, the direct effects of supply disruptions (the Gulf War) and indirect effects through global macroeconomic shocks (the global financial crisis) can be analyzed. Fourth, the robustness of the results using multiple well-established methodologies to assess breaks, causality and cointegration is an important output given the popularity of new untried methods in the literature. Finally, through using Brent crude spot and futures prices, it considers a different dataset to the majority of existing studies. The paper unfolds as follows: Section 4.3 reviews the key extant literature; Section 4.4 describes the data and the methodological approach employed to better understand oil price behavior; Section 4.5 presents the key findings; and Section 4.6 concludes the study.

4.3 Oil Spot and Futures Prices

The dynamic relationship between Brent spot and futures prices has been well analyzed (Crowder and Hamed, 1993; Sadorsky, 1999; Bekiros and Diks, 2008; Mehrara and Hamildar, 2014), leading to calls for research on oil price performance during times of financial turmoil. The existing evidence shows that the relationship between spot and futures prices changes over time and macroeconomic events significantly impact and influence oil behavior (Kim, 2015). Identifying which price leads in stable and crises periods offers valuable information for market participants who would be able to adjust their investment and hedging strategies according to prices dynamics over different time periods.

It has been noted that when there is a high growth rate in the global economy, there is a fear of shortage of petroleum products in the future (Chardon, 2007). However, there have been arguments as to whether changes in energy prices can lead or lag the economic growth cycle. For example, Hamilton (1983) analyzed pre-1972 energy prices and found that energy prices were countercyclical.

However, his work was questioned by Mork (1988) who pointed out that Hamilton's (1983) data contained mostly upward price movements, which could give invalid results in that the correlation between oil prices and economic growth could indicate the existence of asymmetries. Mork (1988) further noted that asymmetry in the correlation between oil prices and Gross National Product (GNP) may exist. In oil exporting countries, high oil prices, based on rising global demand for oil, create an inflow of oil derived revenues, thus increasing economic growth. If oil prices stabilize at too high levels, oil importing countries can experience a decline in economic growth, causing a decline in demand and subsequently in oil prices, which will eventually result in declining revenues for oil exporting countries (Priog, 2005). Additionally, high oil prices may also lead to an increase in exploration activities, which in due course will increase oil supply and cause oil prices to decline over time.

The behavior of oil prices not only depends on current supply and demand, but also on projected future supply and demand. Zhang and Wang (2013) and Forni et al. (2015) found that estimating future supply and demand is challenging when market conditions are uncertain and are changing rapidly. There can also be significant lags in production target adjustments in response to market conditions, which can also impact on prices. Lardic and Mignon (2008) and Wang (2013) noted that economic activity reacts asymmetrically to oil price shocks in that raising oil prices seems to slow down aggregate economic activity by more than falling oil prices stimulate it. Hanabusa (2009) suggested that the high oil prices experienced in 2004 had a serious impact on the Japanese economy, an economy characterized as being highly dependent on oil imports, thereby contributing to aggravate the long lasting recession that the country faced since the early 1980s. The crude oil market is affected by many economic and non-economic factors, like for example, demand and supply shocks, and global, political, economic and geopolitical risks (Ozdemir et al., 2013). During times of uncertainty, managing risk and the price discovery process becomes vital for oil dependent

nations. In this regard, the global financial crisis constitutes a significant episode that affected both the global economy and that spread to the oil market (Borio and Disyatat, 2011). Both spot and futures prices were affected by these events causing abnormal increases and falls in prices.

The extant literature looking at spot and future prices dynamics is in conflict relating to the nature of the relationship between the two prices. Zhang and Wang (2013) analyzed crude oil spot and futures prices finding that futures prices are a better crude oil price indicator than spot prices. The reasoning behind their argument was that the crude oil futures market was launched at a time of high demand for crude oil and dramatic oil price volatility. Moreover, since the crude oil futures market was launched by NYMEX in 1983, it has become one of the largest and most mature futures markets worldwide, and it has played an important role in international financial stability and economic growth. Furthermore, crude oil trading often uses crude oil futures prices as a benchmark (Alquist and Killian, 2010). Due to relatively lower transaction costs and the wider use of short selling mechanisms the crude oil futures market may respond more quickly to new market information than the spot market, therefore making futures prices more efficient. Although, crude oil spot prices can reflect supply and demand levels in a timely manner, futures prices may provide a reference for spot prices, which may lead to a dominant position for crude oil futures prices. Evidence for the alternative view is provided by Pindyck (2001), who studied the effect of futures trading on prices of the Brent crude oil spot market. He found that the existence of futures markets improved the quality of information flowing to the spot markets. Thus, spot prices reflected more quickly the changes that occur in demand and supply conditions. He concluded that there was no evidence of one price leading or lagging the other, and that both prices are mainly influenced by outside factors.

Existing studies identify the presence of long term relationships between spot and futures prices (Garbade and Silber, 1983; Serletis and Banack, 1990; Bekiros and Diks, 2008). In this regard, an

early study based on high frequency data by Schwarz and Szakmary (1994) showed that futures markets dominate spot markets in the oil price discovery process, a finding confirmed by Gulen (1998). Silvapulle and Moosa (1999) noted that crude oil futures prices lead spot prices and found a bi-directional effect indicating that both spot and futures prices react simultaneously to new information. Likewise, more recent research looking at oil futures and spot prices relationships found evidence of cointegration relationships (Lee and Zeng, 2011; Chen et al., 2014). The research findings of Lee and Zheng (2011) also indicate that in shock periods, higher spot prices responded to futures markets more than in the case of lower spot prices. These findings are consistent with Kahneman and Tversky (1979) who also found a stronger cointegration relationship during periods where the market experienced significant losses in comparison to periods of gains. This seems to suggest that when analyzing crises and stable periods, the expected relationship between spot and futures prices should be stronger during shock periods than during stable ones. Wang and Wu (2013) revisit the cointegration relationship between crude oil spot and futures prices, finding that for lower frequency data (monthly or quarterly) the long run relationship is significant and both prices run each other towards the long run equilibrium. This makes it more difficult to decide which price should be monitored more closely when making investment decisions. However, they found that for higher frequency data (weekly) futures prices can drive spot prices. Mamatzakis and Remoundos (2011) also conducted cointegration analysis on the Brent crude oil spot and futures prices using daily spot and futures prices from 1990 until 2009, and their findings show the presence of cointegration between the two variables. The findings of Mamatzakis and Remoundos (2011) demonstrate that in the crude oil market, long run relationships can be used as a good indicator of oil price behavior. For the period between 2005 and 2011, Zhang and Wang (2013) used daily data to test a long run relationship between crude oil spot and futures prices. Their findings showed evidence of long run relationships between spot and futures oil prices supporting earlier findings indicating that both

prices are moving together in the long run. This finding is also consistent with Chang and Lee (2015) who analyzed WTI spot and futures prices between 1986 and 2014.

More comprehensive studies, such as that by Bekiros and Diks (2008), aimed to analyze both the long and short term relationship between crude spot and futures prices. Their main objective was to test if any of the two variables have extra importance during long and/or short run periods. They used the conventional linear Granger (1969) causality test to support their analysis and they found that neither of the variables leads nor lags the other in a consistent manner over time. As a result, from a decision making perspective neither of the two prices can be taken as a key indicator. On the other hand, Haung et al. (2009) found that in periods of higher futures prices than spot prices there is at least one causal relationship between both prices. Kaufmann and Ullman (2009) also found relatively weak evidence of causal relationships between spot and futures oil prices, where futures prices seem to dominate spot prices. A more recent study by Ding et al. (2014) examined the causal relationship between crude oil prices and futures, finding that futures prices in some instances, work as an underlying mechanism of spot prices. This occurs in periods where there are higher returns. These returns encourage speculation in the futures markets which in turn increases futures prices and puts upward pressure on the spot price. Ding et al. (2014) add to the ongoing debate regarding increases in oil prices pointing out that they may be due to sharp increases in speculative positions in the oil derivatives market. Similarly, Gulley and Tilton (2014) test the effect of speculation in futures markets on spot prices. Their findings suggest that in periods of strong contango this is more evident than in cases of weak contango or backwardation. Others argue that oil prices are not influenced by speculative activities (Hamilton, 2009 and 2014), while other lines of research claim that the speculative pressures in the futures market increase crude oil prices (Singleton, 2013). If speculation in the crude market has an influence on its price formation, it would mean that derivative markets, which include the oil futures market, would have a bigger impact on oil price behavior than spot

prices, which are mainly influenced by supply and demand activities. Candelon et al. (2013) also applied Granger causality testing in their analysis of the oil market. More specifically, they were interested in any behavioral changes in periods of upturn or downturn in the market. Their findings showed that both spot and futures prices of Brent crude oil are very important price setters during extreme price movements, in both upturns and downturns, supporting Bekiros and Diks (2008) who indicated the importance of both prices. Moreover, they explain that the existence of bi-directional causality may indicate a changing pattern of the lead and lag relationships over time. But surprisingly, available research studies do not seem to pay sufficient attention to prices dynamics before, during and after a crisis event and the nature of the market shock and its association with the oil prices, a research gap that this paper addresses.

In theory, the futures market often plays a bigger role in the price discovery process, but in practice the spot market may also play an important role (Zhang and Wang, 2013). A causal linkage from crude oil spot to futures prices may be due to the sequence of actions of futures market participants following a spot price change (Moosa, 1996). Zhang and Wang (2013) demonstrate that futures prices are a better price indicator for crude oil than spot prices. Therefore, futures prices appear to have a dominant role in the crude oil market when compared with spot prices, but at the same time the evidence of a causal relationship does not appear to be as strong as the long term association. Moreover, Chang and Lee (2015) point out that the short term relationship is more evident in shorter maturities than in longer maturity pairs. Kim (2015) examined the impact of speculation through futures markets on crude oil market and found that speculation has a positive impact on crude oil markets during the recent “financialization” period. The main insight from the reviewed literature shows clear evidence of disagreement between results regarding the relationship between futures and spot oil prices, which interestingly points out to a dearth of research examining crises periods, which leads to the need of further research in this field.

4.4 Data and Research Framework

4.4.1 Data Insights

The data gathered for this study comprises Brent closing daily spot and continuous¹⁵ futures prices from 7 December 1988 until 31 December 2013, which gives sufficient number of observations to analyze the historical behavior of crude oil spot and futures prices. The 25-year period includes main oil price shocks affecting both spot and futures prices, which helps to analyze oil markets dynamics. Data availability for spot and future prices (as per DataStream records) is recorded from December 1988, and 2013 is the cutoff point to exclude any oil price jumps after this date as the analysis concentrates purely on the two crises that generated great disruption in the oil market and that impacted the behavior of spot and future prices. The data set was obtained from Thomson Reuters Eikon and DataStream. Oil prices were used to test for cointegration; this type of testing is done on non-stationary variables as it could lead to stationary errors that would show evidence of cointegration (Engle-Granger, 1987; Johansen, 1988), and oil prices as returns, as stationary data, are applied for causality examination (Granger, 1969). After a preliminary structural break analysis, this paper concentrates on the time frame before, during and after the first Gulf War and global financial crises periods as they clearly impact the oil markets supply and demand respectively. This allows us to analyze and compare oil prices behavior during two major crises and also during relatively stable periods before and after the crises. As a result, the period from 13 April 1996 to 31 December 2002 was removed from the sample, as it contains events that are not directly connected to supply and demand shocks that may affect our data series such as the Asian Crisis (associated with a regional impact, rather than a global effect) or the Dot-com bubble events that created market uncertainty but that are not clearly connected to supply or demand side effects on oil markets. In contrast, during the first Gulf War a supply shock was clearly identified, and during the global financial crisis a demand

¹⁵ Continuous futures prices are not real futures contracts, but they are made of several futures contracts that have been spliced together to create a long term time series.

shock associated with liquidity constraints with repercussions for the oil sector was identified. Therefore, the selected crises events created significant levels of market uncertainty that are connected to demand and supply shocks that are core points of interest to this research. The data period ends in 2013 to avoid the confounding effect of other possible events that would potentially cause a structural break and also the noise that would be created in the data due to the economic recovery process that preceded the global financial turmoil. The world economies also started to show signs of recovery at different levels around 2013 (Karanikolos et al., 2013; Reinhart and Rogoff, 2014), where some regions were submerged by their own crises dynamics, for example Europe, and as such adding a period after this date would not add to this research analysis, where the interest is to understand oil prices dynamics during events associated with significant uncertainty that transferred to the oil sector. After 2013, additional disruptions associated with the lag effect of the GFC effects needed to be avoided to remove the potential of noise affecting models estimations. The dataset is subsequently split into two main sub-periods, based on structural break tests outcomes to identify and confirm the breakpoint associated with each event. The aim is to investigate the existence of long and short run relationships during period 1 (7 December 1988 to 12 April 1996) and period 2 (1 January 2003 to 31 December 2013). With the help of the Bai-Perron structural break test, these two periods were subsequently split into pre-crisis, crisis and post-crisis periods allowing the examination of changes in behavior during times of relative stability and times of significant market uncertainty. The first period under analysis (7 December 1988 until 12 April 1996) focuses its attention on the Gulf War, as it is directly connected to the oil markets and therefore the relationship between Brent Crude Oil spot and futures may exhibit different behavior when compared to the second sub-sample (1 January 2003 until 31 December 2013) that looks into the impact of a more general event like the global financial crisis on oil prices.

The mean equations considered to model the relationship between spot and futures prices are outlined below:

$$Brent_t = \beta_0 + \beta_1 * BrentF_t + \varepsilon_t \quad (4.1)$$

$$BrentF_t = \beta_0 + \beta_1 * Brent_t + \varepsilon_t \quad (4.2)$$

Where Brent refers to Brent Crude Oil Spot; BrentF is Brent Crude Oil Futures; ε denotes the Error Term; and t is Time Series Daily Data.

4.4.2 Selected Research Methodology

The methodology is supported by stationarity analysis, where the well-known Augmented Dickey-Fuller test (ADF) is applied (Dickey and Fuller 1979). Subsequently, structural breaks, cointegration and causality tests are implemented. These methodologies were selected in line with the extant literature (Bekiros and Diks 2008; Zhang and Wang 2013; Ding et al., 2014) that focuses on the relationship between oil spot and futures prices and that indicates that the chosen methods are considered robust among researchers in the field.

4.4.2.1 Structural Breaks

To identify the particular break points for the two series, the Chow test, Quandt-Andrews test and Bai-Perron test were considered. The Chow test (Chow 1960) consists of breaking the sample into two or more structures.

$$F = \frac{(SSR_n - (SSR_{n_1} + SSR_{n_2}))/k}{(SSR_{n_1} + SSR_{n_2})/(n_1 + n_2 + 2k)} \quad (4.3)$$

The Quandt-Andrews test is an extension to the Chow test and it is used in situations where the break-date is unknown (Hansen, 2001). Quandt (1960) proposed taking the largest Chow statistic over all possible break-dates which is the likelihood test under normality. The Bai-Perron test identifies multiple structural breaks. This test examines the break points between multiple variables simultaneously. The recommended number of break points is five (Mensi et al., 2014), an approach that was followed in this paper, as the point was to confirm the existence of structural breaks around two major periods. Bai and Perron (1998) main framework of analysis can be described by the following multiple linear regression with m breaks (or $m+1$ regimes):

$$y_t = x_t' \beta + z_t' \delta_j + \mu_t ; \quad t = T_{j-1} + 1, \dots, T_j \quad (4.4)$$

for $j = 1, \dots, m+1$. In this model, y_t is the observed dependent variable at time t ; both for x_t ($p \times 1$) and z_t ($q \times 1$) are vectors of covariates and β and δ_j ($j = 1, \dots, m + 1$) are the corresponding vectors of coefficients; μ_t is the disturbance at time t . Break points are explicitly treated as unknown; $T_0 = 0$ and $T_{m+1} = T$ are used. The objective is to estimate the unknown regression coefficients together with the break points when T observations (y_t, x_t, z_t) are available. This is a partial change model since the parameter vector β is not subject to shifts and is estimated using the entire sample (Bai and Perron, 2003). A combination of tests was used to ensure that the changes in our data series were robust to different methods. While further methodologies exist, the outcomes of the three tests chosen were quite consistent thus obviating the need for further testing in this regard.

4.4.2.2 Cointegration

Cointegration techniques are used to investigate the presence of a long term relationship between variables. The selected research methodology offers insights into the kind of relationship that

characterizes oil prices by comparing the outcomes for the Gulf War and the global financial crisis. The Johansen cointegration test (Johansen, 1988) was applied in combination with the Engle and Granger (1987) approach, thus permitting cross checking of the results and identifying if the outcomes from both tests were consistent. The Johansen (1988) approach extends the single equation error correction model to a multivariate one. Let's assume that there are three endogenous variables y_t , x_t and w_t and the matrix notation is $Z_t = [y_t, x_t, w_t]$

$$Z_t = A_1 Z_{t-1} + A_2 Z_{t-2} + \dots + A_k Z_{t-k} + \mu_t \quad (4.5)$$

The above equation is equivalent to the single equation dynamic model for two variables y_t and x_t . It can be reformulated in a vector error correction model (VECM) as:

$$\Delta Z_t = \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \dots + \Gamma_{k-1} \Delta Z_{t-k-1} + \Pi Z_{t-1} + \mu_t \quad (4.6)$$

where $\Gamma_i = (I - A_1 - A_2 - \dots - A_k)$ ($i = 1, 2, \dots, k-1$) and $\Pi = -(I - A_1 - A_2 - \dots - A_k)$.

4.4.2.3 Causality

Causality modelling is used to identify short term relationships and their direction of influence by looking at short run movements on a continuous basis. The well-established Granger Causality test (Granger 1969) was implemented, where two stationary variables are regressed against each other in two separate equations.

$$y_t = \alpha_1 + \sum_{i=1}^n \beta_i x_{t-i} + \sum_{j=1}^m \gamma_j y_{t-j} + \varepsilon_{1t} \quad (4.7)$$

$$x_t = \alpha_2 + \sum_{i=1}^n \theta_i x_{t-i} + \sum_{j=1}^m \delta_j y_{t-j} + \varepsilon_{2t} \quad (4.8)$$

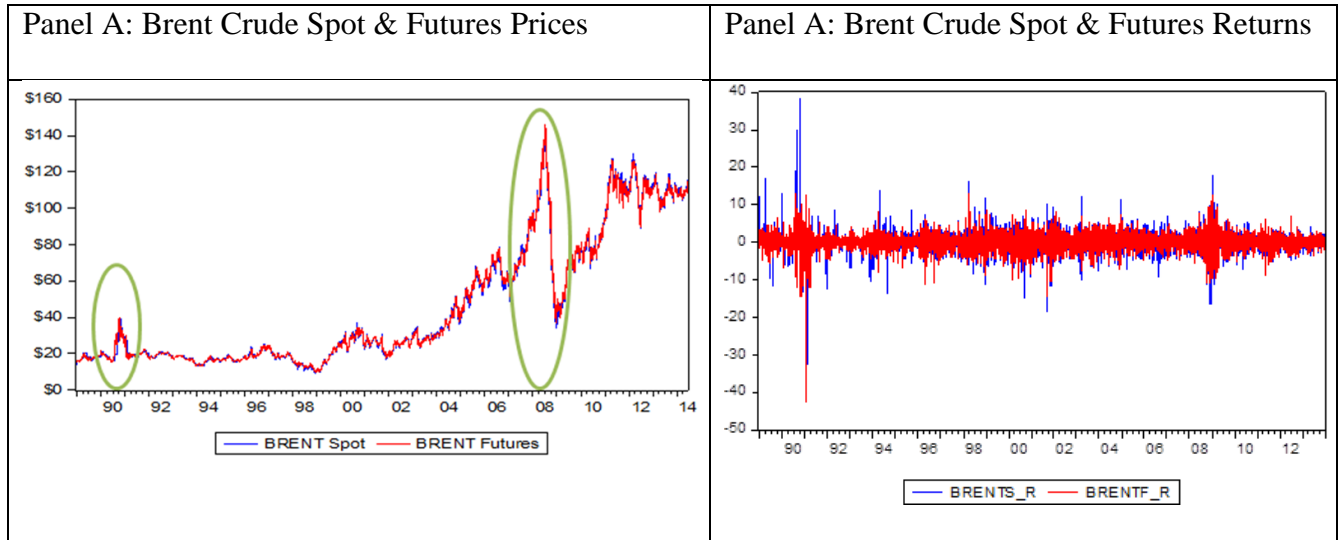
In the case of Brent Crude oil spot and futures prices, Zhang and Wang (2013) identified that at some points in time spot prices cause futures prices. The presented research methodology was carefully selected to ensure that the long and short run relationship between the series under study were properly analyzed and consistent with econometric techniques available and commonly used by researchers in the field and that aligned with extant research and updated studies (Bekiros and Diks, 2008; Lee and Zeng, 2011; Mamatzakis and Remoundos, 2011; Candelon et al., 2013; Wang and Wu, 2013; Ding et al., 2014).

4.5 Research Findings

Descriptive statistics for Brent crude oil spot and futures prices are shown in Table 4.1. Plots of the prices and returns are shown in Figure 4.1. Both variables are presented in terms of levels (prices) and returns. The standard deviation shows significant fluctuations for both variables. Considering the long time period, which includes major events, the values exhibit an overall positive upward sloping trend. The skewness coefficients show that Brent spot and futures prices and Brent spot returns are skewed to the right meaning that the distribution with asymmetric tail extends to positive values, which indicates that oil prices and oil returns are distributed to the right of the mean value. This could be interpreted as an indication of possible upward sloping trends followed by investors and market participants that could be used to base their decisions upon by indicating that the future value will be higher than the mean value now. In the case of Brent future returns, the normal distribution is skewed to the left indicating a difference between spot and futures price returns. Skewness and kurtosis both indicate that the series have a non-normal distribution. The Jarque-Bera test confirms

that the data series are non-normally distributed, aspects that are considered as common characteristics of financial time series (Vo, 2009).

Figure 4.1: Oil Prices and Returns



Source: Thomson Reuters Datastream with graphical additions by the authors (2016)

Table 4.1: Descriptive Statistics

	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
Levels							
Brent Spot	44.39324	143.60000	9.14000	34.39461	1.05078	2.70949	1,226.50500
Brent							
Futures	44.42741	146.08000	9.64000	34.26100	1.03409	2.67205	1,194.88200
Returns							
Brent Spot	0.03122	38.56926	-32.48684	2.263684	0.639295	33.6616	2,56593.0
Brent							
Futures	0.03155	13.15063	-42.72233	2.197838	-1.334978	28.7053	1,81973.1

Structural breaks are a key part of this analysis, as they help to divide the research sample into stable and crises periods. The three structural break tests which were described in the methodology section are applied. For period 1 and period 2, the Bai-Perron test identified five structural break points, and the appropriate break points were used to split the sample. In period 1, the selected break point dates were supported by the Chow test; however for period 2, the beginning of the crisis period date was not confirmed by the Chow test. In order to keep the analysis consistent, the Bai-Perron (1988) test was used for both periods, as it is considered a more refined technique when identifying structural breakpoints, as it can examine multiple break points simultaneously, giving more options than the Chow test, which can identify only one point at a time (Bai and Perron, 2003). Furthermore the Bai-Perron test is widely used (Zhang et al., 2009; Lee et al., 2010; Mensi et al., 2014) among researchers when examining crude oil markets. The test outcomes showed a sequence of break dates which are in alignment with the crises periods under investigation within this study.

The main breakpoints that were considered are outlined in Table 4.2, and they were divided into pre-crisis, crisis and post-crisis periods, allowing the development of a rich analysis regarding relationships between spot and futures prices during different periods that include times of relative stability in the markets and two major shocks. Table 4.2 also presents the outcomes for the unit root test using the ADF test. The results show that Brent spot and futures prices are non-stationary in levels, but are stationary in returns. Robe and Wallen (2016), Bekiros and Diks (2008) and Zivot and Andrews (1992) found that crude oil prices have a unit root in levels and are stationary in returns, and therefore they used oil returns for subsequent analysis, an approach that is also followed in this paper.

Table 4.2: Time Periods and Unit Root Tests

Augmented Dickey-Fuller Unit Root Test for Stationarity

	Period 1: The Gulf War				Period 2: The Global Financial Crisis			
Dates	7/12/1988 to 12/4/1996	7/12/1988 to 27/9/1990	28/9/1990 to 1/4/1991	2/4/1991 to 12/4/1996	1/1/2003 to 31/12/2013	1/1/2003 to 28/8/2007	29/8/2007 to 28/1/2009	29/1/2009 to 31/12/2013
Variables	Whole Period	Pre-crisis	Crisis	Post-crisis	Whole Period	Pre-crisis	Crisis	Post-crisis
Spot in Levels	-2.805107	-0.99903	-0.7798	-1.808944	-1.503	-1.126407	-0.0389	-2.376606
Futures in Levels	-2.305549	3.320726**	-1.8049	-1.941639	-1.549697	-1.022451	-0.18332	-2.344991
Spot in Returns	-44.04343*	-21.7075*	-16.293*	-36.95228*	-54.95103*	-37.44871*	-19.0099*	- 35.54672*
Futures in Returns	-18.11764*	-19.8558*	-11.428*	-23.60717*	-56.92346*	-37.09858*	-21.0706*	- 36.99531*

Note: * denotes significance level at 99 percent level, **denotes significance at 95 percent level

4.5.1 Price Dynamics during the Gulf War

The long term relationship between the Brent Crude spot and futures prices is presented in Table 4.3 below, showing that for the entire Gulf War period, there is evidence of a bi-directional long term relationship. This implies that spot and futures prices move together in the long run and both prices have an influence on oil price formation, a finding that corroborates Zhang and Wang (2013) who used the Johansen cointegration test. A bi-directional relationship is also present for the pre-crisis period, where both prices behaved in a similar way. However, in the cases of crisis and post-crisis periods, the Johansen test identified a uni-directional relationship, where Brent futures prices influence Brent spot prices. This implies that in those two periods, futures prices have more importance for market participants. The results from the Engle-Granger cointegration test showed a strong level of cointegration for the whole Gulf War period and also for the post-crisis period. This result is consistent with Mamatzakis and Remoundos (2011) who analyzed a data set of daily oil spot and futures prices data between 1990 and 2009, and found evidence of the presence of a cointegration relationship. In the pre-crisis and crisis periods, the Engle-Granger test indicated a weak form of bi-directional cointegration.

Table 4.3: Cointegration Analysis for the Gulf War Period

	Johansen Cointegration Test	Engle-Granger Test
Whole Period	Cointegration**	Bi-directional Cointegration*
Pre-Crisis	Cointegration**	Bi-directional Cointegration***
Crisis	Cointegration**	Bi-directional Cointegration**
Post-Crisis	Cointegration**	Bi-directional Cointegration*

Note: *denotes significance level at 99 percent, ** denotes significance at 95 percent level, and *** denotes 90 percent significance level. In the case of the uni-directional findings, futures prices influence spot prices.

The Johansen model indicates the existence of a cointegration relationship for the whole of the Gulf War period and also for the pre-crisis period. This suggests that the futures and spot prices are influencing each other in the long run; however it cannot be established which variable is more important, or in other words, which one leads the other. In the crisis and post-crisis period, the Johansen test also found evidence of cointegration between Brent futures and spot prices at a 95 percent significance level. The Engle-Granger test confirms the existence of bi-directional relationships for the pre-crisis and whole Gulf War period, however in the case of the pre-crisis period the cointegration relationship from Brent futures to Brent spot was identified at a 90 percent significance level that is considered as a weak result. The two tests are consistent with regard to the main outcomes, and overall it can be said that there is a strong long term relationship between both variables for the studied periods. In this regard, the obtained results are very consistent with earlier studies such as Serletis and Banack (1990), who also found evidence of long term relationships between crude oil spot and futures prices. The analysis however, does not give a clear indication regarding which variable is leading the other. This suggests that during the whole Gulf war period both prices appeared to exhibit a similar degree of importance as a price indicator, a result that contradicts those findings that suggest that future prices are the leading indicator in terms of price formation (Garbade and Silber, 1983; Bekiros and Diks, 2008). Consequently, periods of sustained market instability need to be considered carefully, as they impact prices dynamics that are affected by the source of the market shock.

The Granger Causality test (see Table 4.4 below) indicates a bi-directional short term relationship for the whole period and for the pre-crisis period. During the crisis period the test demonstrated a uni-directional relationship caused by spot prices, indicating that spot prices influenced futures prices during the period. This could be explained by an immediate reaction

to the economic situation and the subsequent oil industry response. However, during the post-crisis period, the uni-directional relationship revealed an influence from futures to spot prices, which may be driven by the derivatives markets reaction to higher risks and uncertainty affecting the market. This may have influenced market participants in their decisions and investment strategies, thereby making them more inclined to reduce the risks associated with oil price changes by pursuing hedging strategies through derivative markets. These positions can be linked with long run (pension or endowment funds) or short run (speculative) decisions, where investors can materialize gains/losses depending on their long/short positions.

The results showed that for the whole Gulf War period there is a strong causal relationship caused by futures prices. However, this result may be biased, as it does not account for further structural breaks that could be affecting the series during this particular period. Brent futures prices appear to be influencing the creation of Brent spot prices, a research finding that is supported by Garbade and Silber (1983) and Bekiros and Diks (2008). This is important information for market participants and policy makers, as in the short run futures prices seem to be a better price indicator and therefore competitive advantage could be gained through monitoring them.

The Granger Causality test and the VECM model showed evidence of a uni-directional relationship in the post-crisis period between prices. More specifically, Brent futures caused Brent spot prices in the post-crisis period. This finding supports the analysis by Ding et al., (2014) who suggested that oil futures prices work as an underlying mechanism in the formation of crude oil spot prices. During the crisis period, the Granger Causality test indicated a uni-directional short term relationship, but when the corrected VECM model for

cointegration was applied, no short term relationship was found between the Brent spot and futures prices as per Table 4.4. This outcome suggests that there is no obvious short term directionality between spot and futures prices during the Gulf War. Therefore, it seems it is more challenging to predict price behavior in the short run during times of crises due to higher levels of uncertainty, and also due to a higher sensitivity to risk and negative information in the market. This is perhaps unsurprising given the impact of crisis events on the identification of price patterns.

Table 4.4: Causality for Gulf War Period

	Granger Causality	VECM
Whole Period	Bi-directional Causality \leftrightarrow	Uni-directional Causality \leftarrow
Pre-Crisis	Bi-directional Causality \leftrightarrow	Bi-directional Causality \leftrightarrow
Crisis	Uni-directional Causality \rightarrow	No Causal Relationship
Post-Crisis	Uni-directional Causality \leftarrow	Uni-directional Causality \leftarrow

Note: \rightarrow indicates that Brent cause BrentF, and \leftarrow indicates that BrentF cause Brent, \leftrightarrow indicates bidirectional causal relationship, all at 99 percent significance level for the Granger Tests. The VECM model did not confirm cointegration in any of the periods. BrentF denotes the futures price and Brent the spot price.

4.5.2 Price Dynamics during the Global Financial Crisis

The global financial crisis had no direct connection to the oil markets; however, the rapid changes in the financial system and property markets had a knock-on effect triggering major disturbances in the oil markets from demand side effects through market liquidity issues, where the financial institutions were highly leveraged associated with funding problems that impacted many sectors. This could have activated unusual behavior between oil spot and futures prices, which would have implications for oil market participants, hedgers, speculators and policy makers. The cointegration results in Table 4.5 indicate the existence a

long run relationship between the two variables for the whole period of the global financial crisis, outcomes that were mirrored in both the pre-crisis and crisis periods.

Table 4.5: Cointegration Analysis for the Global Financial Crisis

	Johansen Cointegration Test	Engle-Granger Test
Whole Period	Cointegration**	Bi-directional Cointegration*
Pre-Crisis	Cointegration**	Bi-directional Cointegration*
Crisis	Cointegration**	Bi-directional Cointegration*
Post-Crisis	Cointegration**	Bi-directional Cointegration*

Note: *denotes significance level at 99 percent level, ** denotes significance at 95 percent level

The Engle-Granger test shows a bi-directional relationship between spot and futures prices for the whole period of the global financial crisis, and also for all sub periods, suggesting that the spot and futures prices behaved in a similar way in both stable and crises periods. These research findings are consistent with those of Bekiros and Diks (2008), who suggested that even though futures prices may be considered more important as a price discovery mechanism, the spot market is also an important player.

Similar to the procedure followed for the Gulf War period, causality tests were applied to the global financial crisis period. The Granger causality test results in Table 4.6 indicate a bi-directional relationship between oil spot and futures prices for the whole crisis period. However, all sub periods showed a strong uni-directional relationship caused by futures prices. Once more, these findings align with the Bekiros and Diks (2008) results, who noted that even though futures prices may be more important in the oil price discovery process, spot prices cannot be forgotten as they are also relevant.

Table 4.6: Causality Analysis for the Global Financial Crisis

	Granger Causality	VECM Causality
Whole Period	Bi-directional Causality \leftrightarrow	No Causal Relationship
Pre-Crisis	Uni-directional Causality \leftarrow	Uni-directional Causality \leftarrow
Crisis	Uni-directional Causality \leftarrow	No Causal Relationship
Post-Crisis	Uni-directional Causality \leftarrow	No Causal Relationship

Note: \rightarrow indicates that Brent causes BrentF, and \leftarrow indicates that BrentF causes Brent, and \leftrightarrow indicates bidirectional causal relationship, all at 99 percent significance level.

The VECM model (Table 4.6), does not find significant evidence of a short term relationship for the crisis and the post-crisis sub-periods and for the entire period, but it confirms a uni-directional relationship for the pre-crisis period caused by Brent futures prices. The behavior indicates that in general, futures prices have more influence on spot prices in the long run and also in the short run than spot prices on futures prices. This is consistent with the findings of Silvapulle and Moosa (1999) who found a uni-directional relationship between crude oil spot and futures prices caused by futures prices, and also with the findings of Bekiros and Diks (2008).

4.5.3 Critical Insights on the Gulf War and the Global Financial Crisis Findings

Extant research suggests that futures prices lead spot prices and therefore play a significant role in the oil market (Gulen, 1998; Sivapulle and Moosa, 1999). Conversely, in this paper, the long run relationship between oil spot and futures prices was found to be significant and bi-directional for both shock periods. Bi-directional cointegration showed that both prices are equally important for both crises periods. This is consistent with both Zhang and Wang (2013) and Bekiros and Diks (2008) who also found evidence of a long run relationship between spot and futures prices. The results obtained from this study after applying the

Engle-Granger test show that for both periods and all sub periods there is a strong bi-directional relationship between oil spot and futures prices. This confirms the views and main findings exhibited by most recent studies (Bekiros and Diks, 2008; Mamatzakis and Remoundos, 2011; Zhang and Wang, 2013), and also suggest that existing research could benefit from the inclusion of sub periods and the use of structural break analysis (Maslyuk and Smith, 2008), which helped to divide the Gulf War and global financial crisis periods into stable and crisis periods in this study.

Secondly, the Granger causality and VECM models were applied to test for presence of short term relationships between oil spot and futures prices. The Granger causality test found bi-directional causality between oil spot and futures prices for the whole period of the Gulf war and the global financial crisis. It also showed a uni-directional relationship for all other sub periods, except the pre-crisis period during the Gulf war sample, where a bi-directional relationship was found at the 99 percent significance level. The VECM model found evidence of a strong short term relationship during the whole Gulf war period caused by futures prices. This result differs from the outcomes for the global financial crisis, where no causal relationship was found, with the exception of the pre-crisis period, where a uni-directional relationship was caused by futures prices. During the Gulf War pre-crisis period, strong bi-directional causality was found at the 99 percent significance level and significant uni-directional relationship in the post-crisis period caused by futures prices. During the global financial crisis and the post-crisis period no short term relationship was found. These findings are consistent with the findings of Ding et al., (2014) who suggest that only in some instances do futures prices lead oil spot prices, and this is dependent on various economic activities and time periods. Zhang and Wang (2013) found bi-directional causality between oil spot and futures prices between 2005 and 2011. However, they included only one structural break

occurring in mid-2007, which might help to explain the inconsistencies with the results of this study. The findings of this study cannot confirm the short term relationship for any of the shock periods; however it suggests that in cases of a uni-directional relationship futures prices tend to lead spot prices.

4.6 Conclusions

This study is focused on the analysis of long and short run relationships between Brent crude oil spot and futures prices during the first Gulf War (1990/91) and the global financial crisis (in the late 2000s). A key contribution of this paper is the analysis of two major crises periods affecting oil prices, which also include relatively stable periods before and after each shock. This offers an in depth outlook of spot and futures prices relationships for six different sub-periods. The main research findings are consistent with the analysis developed by Ding et al. (2014), indicating that futures prices are the underlying instrument in crude oil spot prices, which suggests that market speculation with the help of derivative markets through futures, swaps and options, may be a driver of crude oil prices. This is in contrast with the findings of Hamilton (2009) who argues that speculation does not influence oil price behavior, but that it is down to fundamentals such as oil supply and demand levels. The lack of a causal relationship due to a direct shock to the oil market (the Gulf War) was an unexpected outcome as was the existence of a causal relationship for an indirect shock to the market (the global financial crisis). It may be that demand-led shocks are more likely to affect the market than supply side shocks or it may be attributed to the magnitude of the global financial crisis.

The above findings confirm the initial hypotheses that tested the lead-lag relationship between oil spot and futures prices changes during both crisis and stable periods, highlighting

the dynamic and complex relationship that exist between both prices. This offers insightful information for oil market participants by providing an alternative view and additional information about how spot and futures prices react to market conditions and how they relate to each other. The analysis offers supplementary information about oil market behavior under different economic scenarios, and puts forward the importance of monitoring closely these markets connections as they are affected by countries economic situation. It is clear given the lack of a clear lead-lag relationship over time that those interested in the oil market need to consider both the spot and the futures markets as the lead-lag relationship is subject to dynamic patterns. The study also highlights the need for further research in the field to help the understanding and discerning of oil prices dynamics under different economic and financial scenarios, as current research is affected by major controversies on their findings and by a lack of distinction between price behavior during times of relative market tranquility and severe distress and by the source of the shock and connection to the oil sector. Future research could extend the study from the two crises studied here to the wider set of events that disrupt the oil market.

Chapter 5 - Paper 2

Brent Crude Oil Spot and Futures Prices Volatility during Times of Major Crises¹⁶

5. 1 Abstract

The performance of Brent crude oil daily spot and continuous futures prices is considered during four major shock periods in the markets: namely, the Gulf war (1990/91), the Asian crisis (1997/98), the US terrorist attack (2001), and the global financial crisis (late 2000s). Volatility patterns are also examined before and after each shock to allow an in-depth understanding of market fluctuations during the selected periods using the GARCH (1,1), T-GARCH (1,1) and OLS methods to test for the existence of volatility persistence patterns. The main research outcomes indicate that in the case of the Gulf war and the US terrorist attack, oil prices were exposed to higher fluctuations than the ones registered during the Asian and the global financial crisis that exhibited longer persistency. The empirical findings also confirmed the existence of asymmetric information during the global financial crisis, with negative news having a greater impact on oil price volatility than good news.

Keywords: Crude Oil; Volatility; Energy; Spot and Futures Prices; Crises

JEL codes: G01, G17, Q40

¹⁶ This paper has been reformatted to fit with the DIT thesis presentation guidelines.

5.2 Introduction

Globally the oil market can be considered as one of the world's largest and most strategic commodities. Oil is an indispensable energy resource to fuel economic growth and development, and industrialised and developed economies consider it to be a key driver of their economies. Oil prices are determined by demand and supply levels, but they are also affected by sources of natural volatility including business cycles, speculative activities, and political influences (Oberndorfer, 2009; Hamilton, 2014; Robe and Wallen, 2016). Furthermore, the non-renewable and scarce nature of oil is an additional factor that justifies the existence of strong price fluctuations in the crude oil market. Such behaviour has a major impact on investment and strategic decisions taken by investors, hedgers, speculators and governments, that need to be aware of higher volatility phases, where higher levels of risk and uncertainty are exhibited in the market, conditioning as a result the decision making process (Sadorsky, 2006; Salisu and Fasanya, 2013; Zhang and Wang, 2013; Morales and Andreosso-O'Callaghan, 2014). Crude oil prices have encountered extreme volatility over the past decades due to numerous factors, such as wars and political instability, economic and financial slowdowns, terrorist attacks, and natural disasters. The identified events have led to great uncertainties in the oil market, which have influenced investors and market participants, as high levels of risk in the market make it very 'hard to predict' oil price patterns. This study considers the relationship between spot and future prices through analysing their behaviour during four specific periods of turmoil characterised by major changes in oil prices: namely the Gulf war, the Asian crisis, the US terrorist attack and the global financial crisis.

In the case of the Gulf war, the main factor driving oil price change was supply disruptions, due to Iraq invading Kuwaiti territory, as these countries accounted for almost 9 percent of

the world production at that time (EIA, 2011). Kuwait and Iraq suffered financial losses in their oil industry causing a decline in their government revenue and putting upward pressure on oil prices leading to a doubling of prices within a few months from \$20 to \$40 per barrel. However, the shock was short-lived as prices returned to pre-conflict levels quite rapidly. This was mainly due to Saudi Arabia's excess capacity, which helped to restore production levels (Hamilton, 2011). On the other hand, the Asian financial crisis did not have a direct connection with the oil market, as it originated in the currency market with the collapse of the Thai baht, which drove Thailand to near bankruptcy. Nevertheless, oil prices were impacted by the reduction in consumption levels due to the financial distress experienced in the region, where China can be identified as the major oil consumer. For illustration, China consumed around 2,300 thousand barrels per day in 1990/91, 4,000 thousand barrels per day in 1997/98, 4,900 in 2001 and 7,700 in 2008 (EIA, 2016). During this period, the price of oil went from \$20 per barrel in 1997 to below \$13 per barrel. The Asian crisis proved to be short-lived, as was also the case of the Gulf war, and by 1999 oil consumption and prices had reverted to their pre-crisis position in 1997. The US terrorist attack, which happened in September 2001, caused panic and had a negative impact on air transport worldwide thus weakening demand for oil for a short period of time. Oil prices decreased by as much as 35 percent by November; however, the OPEC decision to cut production quotas in 2002 sent oil prices rising once again. The global financial crisis, originating in the US subprime market, caused major instability in the financial markets and was transferred to the oil market by a rapid increase and sudden drop in oil prices, primarily caused by a considerable decline in oil needs by the construction and transport sectors. This period was also characterised by a stagnant oil supply and growing demand from emerging countries, which caused a rise in oil prices to historic highs reaching nearly \$150 per barrel by July 2008. However, this oil price rise was

followed by a rapid correction, with prices dropping below \$40 per barrel by the end of 2008, as demand weakened even further (see Figures 5.1 and 5.2 in the next section).

Overall, the presented shocks are characterised by their relatively short duration and their dramatic impact on oil prices that contributed to generating instability in the oil sector though with clear ramifications for the real economy. Therefore, oil price volatility significantly influences the behaviour of oil spot and futures prices, and these fluctuations play an important role for oil markets participants, as their decisions are based on future expectations (Hamilton, 2009; Hamilton, 2014; Mensi et al., 2014). Charles and Darné (2009) claim that changes in oil prices and high oil volatility, due to demand and supply fluctuations, create high degrees of uncertainty for countries and their industries, which are dependent on oil. Subsequently, these factors impact on the overall country's GDP, as high oil prices make production activities more expensive, putting downward pressure on countries output and affecting their economic activity (Sadorsky, 2001).

This paper aims to better understand oil prices dynamics during shock periods with the goal of establishing the nature of oil prices behaviour by analysing the dynamics of oil spot and futures prices. Volatility persistence is studied during the four proposed crisis periods, and the research questions and hypotheses to be addressed are as follows:

- 1) Is oil volatility affected by crises periods?

H_0 : There is no volatility increase during crises periods in the Brent spot and futures prices.

H_A : There is volatility increase during crises periods in the Brent spot and futures prices.

- 2) Are there different outcomes of volatility persistence during different crises periods?

H_0 : There are no differences in volatility persistence between different crises periods.

H_A : There are differences in volatility persistence between different crises and stable periods.

3) Does negative news have a bigger impact on oil volatility than good news?

H_0 : Negative news does not have a bigger impact on volatility than good news.

H_A : Negative news has a bigger impact on volatility than good news.

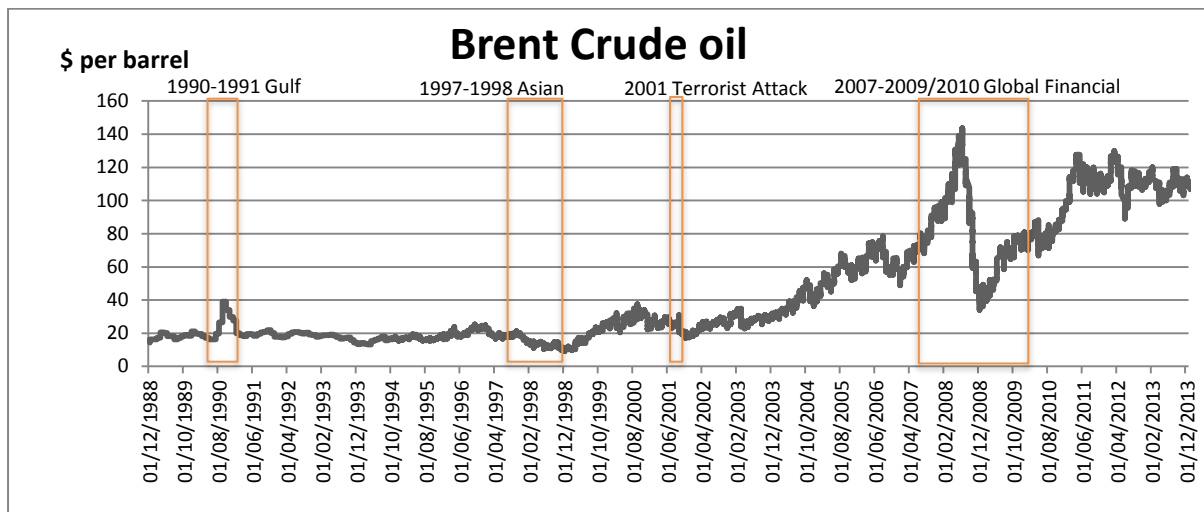
The events under study signal major price changes that need to be considered when analysing oil price dynamics and that to the best of the author's knowledge have not been considered together by the extant literature. Then, this study focuses on the dynamics between spot and futures prices and how they might be subject to differences in behaviour depending on the root causes of the individual crises. This is a situation that could influence oil market participants when deciding to attribute extra importance to spot or futures prices, while making business decisions.

5.3 An Overview of Crude Oil Spot and Futures Price Volatility Persistence

There has been a significant surge in research studies looking at volatility modelling, as academics and practitioners are acutely aware of the significance of understanding financial market volatility (Oberndorfer, 2009; Ozdemir et al., 2013; Salisu and Fasanya, 2013; Zhang and Wang, 2013; Charles and Darné, 2014; Wang et al., 2016). Antoniou and Foster (1992) analysed the effect of futures trading on prices of the underlying spot market of Brent crude oil. The concept behind their study was to test the effect of futures prices and their inherent volatility on spot prices due to concerns about the consequences of derivatives markets. They

used weekly data from January 1986 to July 1990 consisting of 240 observations, and implemented a GARCH model, observing that volatility is dynamic and changes over time, especially in 1986 and in mid-1990. They found that the introduction of the futures markets improved the quality of information flowing to spot markets. Thus, spot prices more quickly reflected the changes that occur in demand and supply conditions, and they also found that both prices are influenced by outside factors. Crude oil price volatility and its behaviour over time was also analysed by Ozdemir et al. (2013). The authors looked at Brent spot and futures price volatility persistence from the 1990s until 2011, finding that volatility was very persistent in both spot and futures prices. Their findings also suggest that spot and futures prices can grow in an unpredictable manner in the long run, which indicates that there is no potential for arbitrage opportunities to materialise for investors in the oil market. Similarly, Charles and Darné (2014) studied volatility persistence from 1985 until 2011. Their main focus was to understand how shocks can affect volatility over time. The outcome of their research suggests that structural breaks affecting the series can impact the estimation of volatility persistence, which may improve our understanding of volatility in crude oil markets. Lee et al. (2006) evaluated the existence of these breaks, finding them to be of great importance to individuals and firms who are concerned about how well they can manage the risks associated with frequent changes in oil prices. Narayan and Narayan (2007) were also two of the first authors attempting to model and forecast oil price volatility using different sub-samples. The presence of structural break points confirms abnormal behaviour in the series, which indicates higher uncertainty and an elevated level of risk which should be accounted for by concerned groups of investors, speculators and policy makers. The findings of these papers are included in the current study through explicit consideration of the importance of structural breaks when modelling oil volatility through applying multiple break points to analyse all four shock periods (see highlighted areas in Figure 5.1).

Figure 5.1: Historical Development of Brent Crude Oil Price



Source: Thompson Reuters Datastream (graphical adjustments added by the authors, 2016)

The four episodes were chosen for analysis, as they are associated with periods of significant changes in oil prices, as illustrated in Table 5.1 below.

Table 5.1: Oil Price Changes*

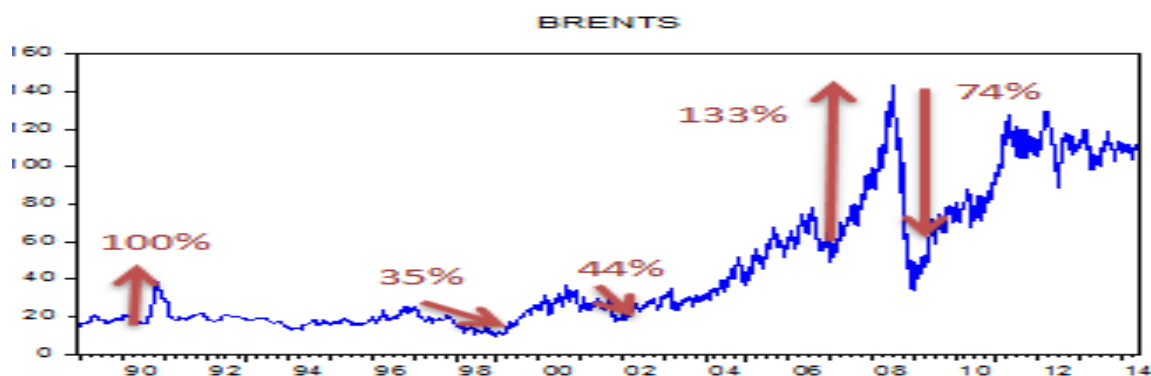
	Price Change
The Gulf War	↑ 100%
The Asian Crisis	↓ 35%
US Terrorist Attack	↓ 44%
The Global Financial Crisis	↑ 133% ↓ 74%

*Note: Price changes are calculated as a percentage change of the highest and lowest price in each period. Numbers are rounded to the nearest full number. Source: Author's calculations based on Datastream prices (2016).

During times of uncertainty, managing risks and the price discovery process becomes of vital importance for economic agents that aim to maximise their gains while they minimise their losses. Ozdemir et al. (2013) indicated that various approaches are used in order to describe the price path of crude oil prices. It is widely agreed that a high degree of volatility and strong seasonal components are important features of crude oil prices behaviour. This can be

affected by many factors such as shocks in the economy, natural disasters associated with lower oil supply levels or political instabilities. The Gulf War, the US terrorist attack, the Asian financial crisis and the worldwide turmoil experienced during the global financial crisis, constitute significant episodes that affected both the global economy and the oil market driven by abnormal oil price changes. Both spot and futures prices were affected by these events causing abnormal increases and falls in oil prices as shown in Figure 5.2, which had a negative impact on economic performance by putting a financial constraint on oil dependent industries. This had a consequent undesirable effect on the real economy. In the next sections we review recent studies, which examined the four events that are the focus of this study.

Figure 5.2: Four Major Rises and Falls of Brent Oil Prices



Source: Thompson Reuters Datastream (graphical adjustments added by the authors, 2016)

5.1.1 The Gulf War

Salisu and Fasanya (2013) examined Brent and West Texas Intermediate (WTI) volatility with structural breaks from 1986 to 2012. The authors identified two structural breaks, the first one occurring in 1990, corresponding to the Iraqi/Kuwaiti conflict (the Gulf war), and the second one took place in 2008, reflecting the global financial crisis using the NP

(Narayan and Popp, 2010) test. The main focus of their study was to examine volatility behaviour and persistence using GARCH type models. From their results, it is evident that the highest point of volatility occurs at the specified structural breaks points, where the variation in oil prices was very high. They found that the variance process reverts slowly with a high level of persistence. The identified leverage effects indicated that negative shocks have a higher effect on volatility than positive news. The importance of including asymmetries, especially the impact of negative news on oil price volatility, was highlighted in their study. Charles and Darné (2014) examined volatility persistence in Brent and WTI crude oil markets between 1985 and 2011. Several GARCH type volatility and structural break tests were used in their research. They found periods of uncertainty during the Gulf war invasion in 1990, and they found evidence of volatility clustering in this period. Furthermore, their findings showed higher volatility during the Gulf war period than during the global financial crisis period, suggesting that the level of uncertainty in the oil market was higher during the Gulf War period. Park and Ratti (2008) also analysed oil prices, this time considering the period from 1986 to 2005 and they found significant oil price changes during the Gulf war period, which had a negative impact on oil volatility and stock markets.

5.1.2 The Asian Financial Crisis

Ozdemir et al. (2013) analysed Brent spot and futures prices from 1990 to 2010 and found that there were many small structural breaks in the series, but also some significant changes in the series. They found that oil price behaviour differs from January 1991 to November 1998 and from November 1998 until December 2011. More specifically, they noted that the Asian crisis was one of the major periods that affected the global economy and the oil market. From November 1998, they found that high volatility became a noticeable feature of

oil prices (Ozdemir et al., 2013). They also noted that from that period onwards the upward and downward trends had different durations and intensities, and that spot and futures prices behaved differently before and after this shock. Futures prices became more volatile without a mean reversion tendency, but all price series reacted to the same shocks both instantly and simultaneously. Wang and Wu (2012) and later Wang et al. (2016) noted that oil price and volatility are frequently influenced by demand and supply shocks, and found high oil volatility during the Asian crisis in 1997/98, primarily motivated by lower demand for oil.

5.1.3 The US Terrorist Attack 2001

The 2001 US terrorist attack caused a significant decrease in oil prices. The attack generated a temporary effect due to the severe reduction in oil demand as a direct consequence of the shock (Wang et al., 2016), which quickly recovered mainly driven by strong economic activity and the cutting of production quotas imposed by OPEC (Wang and Wu, 2012). Sadorsky (2012) conducted research on the volatility of oil prices and energy stocks between 2001 and 2010, and found large spikes in volatility during September and November 2001, which corresponds to the terrorist attack in the US. He used GARCH type models to test for volatility and found them to be useful for volatility modelling. Wang and Wu (2012) discovered that asymmetric models to test volatility of oil prices worked best in their study as they showed results that were closer to the actual level of volatility. This indicates that oil price volatility can be characterised by significant persistence and asymmetric effects.

5.1.4 The Global Financial Crisis

Brent spot and futures prices experienced structural breaks during the global financial crisis. Ozdemir et al. (2013) found a break both in November 2008 and in December 2011 using the Lumsdaine and Papell (LP) test (1997). They pointed out that when structural breaks are incorporated both spot and futures prices are not as persistent compared to high degrees of persistence when the breaks are not integrated. Their result suggests that both Brent spot and futures prices are unpredictable. Charles and Darné (2014) found atypical volatility movements taking place during December 2008 and January 2009, which can be explained by the financial crisis impacting oil prices. Salisu and Fasanya (2013) also indicated high volatility spikes during this period with a structural break occurring in April 2008 using the NP test. Sadorsky (2012) similarly reported findings of high oil volatility and evidence of volatility clustering between August 2008 and August 2009, which he suggests was caused by the recession having a significant impact on oil prices. Liu et al. (2013) note the existence of high spikes in oil prices in late 2008, which were triggered by the financial crisis. Wang et al. (2016) noted that oil prices were persistently increasing since 2003 driven by an economic boom in emerging economies, but they dropped in the second half of 2008, which they suggest was triggered by the global economic recession. Zhang and Wang (2013), Zhang and Li (2016) and Zhang et al. (2015) also found a shock in oil prices in late 2008, which had negative effect on oil prices. These fluctuations in oil prices affected both the spot and futures markets (Zhang and Wu, 2013).

The methodology section offers the approaches used in this research based on previous studies (Oberndorfer, 2009; Wei et al., 2010; Sadorsky, 2012; Wang and Wu, 2012; Liu et al.,

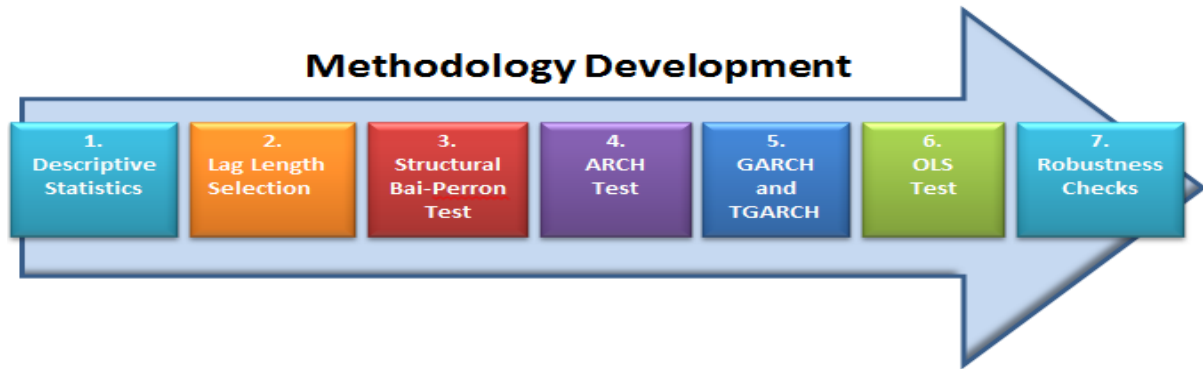
2013; Salisu and Fasanya, 2013; Zhang and Wu, 2013; Charles and Darné, 2014; Wang et al., 2016), which are found suitable for oil volatility forecasting.

5.4 Data and Methodology

The data set consists of daily closing spot and futures prices for the Brent crude oil market. The data was obtained from Thompson Reuters Datastream and is shown in US dollars per barrel. The whole data sample spans from 7th December 1988 to 31st December 2013, which provides 6,540 observations. The use of daily data is particularly relevant for volatility analysis (Salisu and Fasanya, 2013; Charles and Darné, 2014) as higher frequency data is needed in order to capture the changes in the market.

The study begins with a standard analysis of the properties of the selected series. This is followed by basic formal tests including the VAR framework used to identify the optimal lag length for each variable, the Augmented Dickey-Fuller (ADF) test for stationarity and the Bai-Perron structural break test. This is in turn followed by volatility modelling using the GARCH, T-GARCH and OLS approaches. The OLS model is included for comparison purposes and also to deal with those cases where GARCH and T-GARCH models do not perform. Lastly, robustness checks on residuals are included to test for heteroskedasticity and serial correlation to ensure the proper implementation of the GARCH type models. Figure 5.3 depicts the sequence of methodology steps undertaken in this research.

Figure 5.3: Methodology Development



Source: Authors (2016)

The Schwarz criterion (SC) was used for model selection, as it performs slightly better for large samples - over 250 observations - than the Hannan-Quinn (HQ) criterion (Asghar and Abid, 2007; Bouri, 2015). The four shock periods under analysis were verified and subsequently, the sample was split into stable and crises sub-periods through the implementation of structural break tests. To identify the particular break points for the series, the Chow test, Quandt-Andrews test and Bai-Perron tests were considered and their outcomes were crosschecked. The Bai and Perron (1998) test is described by the following multiple linear regression with m breaks (or $m+1$ regimes):

$$y_t = x_t' \beta + z_t' \delta_j + \mu_t \quad t = T_{j-1} + 1, \dots, T_j \quad (5.1)$$

for $j = 1, \dots, m+1$, where m is the number of breaks. In this model, y_t is the observed dependent variable at time t ; both x_t ($p \times 1$) and z_t ($q \times 1$) are vectors of covariates and β and δ_j ($j = 1, \dots, m+1$) are the corresponding vectors of coefficients; μ_t is the disturbance at time t . Break points are explicitly treated as unknown; $T_0 = 0$ and $T_{m+1} = T$ is used. The objective is to estimate the unknown regression coefficients together with the break points when T observations on (y_t, x_t, z_t) are available. This is a partial change model since the

parameter vector β is not subject to shifts and is estimated using the entire sample (Bai and Perron, 2003).

5.4.1 Volatility Models

The univariate models used for forecasting crude oil prices in this study are the Generalised Autoregressive Conditional Heteroskedasticity (GARCH) model presented by Bollerslev (1986), the Threshold GARCH (T-GARCH) model by Zakoian (1994) and the Ordinary Least Squares (OLS) regression model by Johnson (1960), which is used when there is no ARCH¹⁷ effect in our series.

The ARCH model presented by Engle (1982) suggests that the variance of the residuals at the time t depends on the squared error terms from past periods. The ARCH (q) model specification is presented in equation 5.2 below:

$$y_t = \alpha + \beta'x_t + \varepsilon_t \quad (5.2)$$

where, $\varepsilon_t | \Omega_t \sim iid N(0, h_t)$, and

$$h_t = \gamma_0 + \sum_{j=1}^q \gamma_j \varepsilon_{t-j}^2 \quad (5.3)$$

The generalised ARCH model by Bollerslev (1986) known as GARCH (p, q) is outlined as follows:

$$y_t = \alpha + \beta'x_t + \varepsilon_t \quad (5.4)$$

where, $\varepsilon_t | \Omega_t \sim iid N(0, h_t)$, and

$$h_t = \omega + \sum_{i=1}^p \alpha_i h_{t-i} + \sum_{j=1}^q \gamma_j \varepsilon_{t-j}^2 \quad (5.5)$$

¹⁷ The ARCH effect is to test for conditional heteroskedasticity on the residual series.

This states that the value of the variance scaling parameter now depends both on past values of the shocks, which are captured by the lagged squared residual terms, and on the past values of itself, which are captured by lagged terms. The simplest form of GARCH (p, q) model is the GARCH (1, 1), which is commonly used by many researchers in oil markets, as it generally performs better than higher order GARCH models (Lee et al., 2006; Narayan and Narayan, 2007; Salisu and Fasanya, 2013), for which the variance equation is:

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} \quad (5.6)$$

The ARCH and the GARCH models are symmetric; however, it has been observed that negative shocks have greater impact on volatility than positive shocks in most financial time series such as stocks and commodities. Therefore, in order to test for asymmetries in the conditional variance the T-GARCH model was deemed appropriate and included in this analysis. The specification of the conditional variance equation for T-GARCH (1,1) is given by:

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \theta \varepsilon_{t-1}^2 d_{t-1} + \beta h_{t-1} \quad (5.7)$$

where, d_t takes the value of 1 for $\varepsilon_t < 0$, and 0 otherwise. This means that positive and negative shocks have different impacts. Positive news has an impact of α , whereas negative shocks have an impact of $\alpha + \theta$. We also apply the Ordinary Least Squares (OLS) method, which is a model that assumes the existence of constant variance. OLS regression introduced by Johnson (1960) is one of the initial approaches used to model volatility behaviour in time series, and it is applied in this study for comparative reasons and when the samples are too small to allow the ARCH and GARCH type models to run.

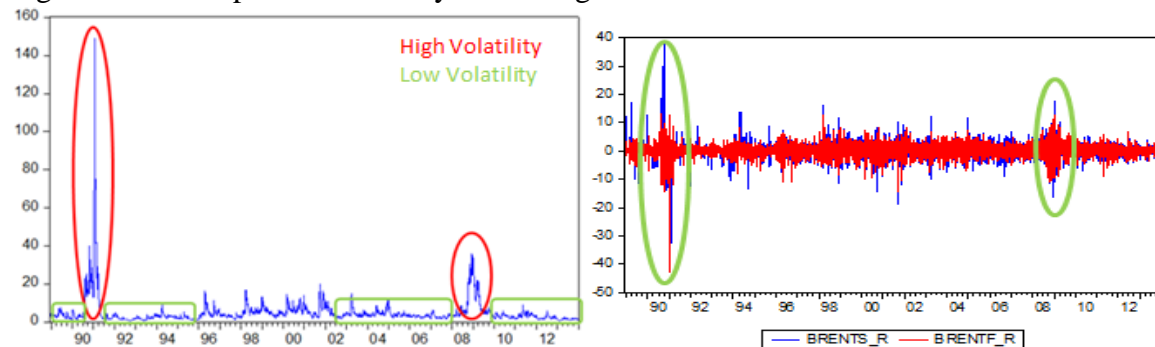
5.5 Empirical Findings

The analysis starts with the presentation of summary statistics in order to review descriptive characteristics of our data and continues with the analysis and discussion of outcomes for the volatility models tested. Appendix A represents the historical development of Brent crude oil spot and futures prices for the whole sample set, and also a graphical representation of their log returns.

5.5.1 Summary Statistics

The data series shows strong evidence of volatility clustering, where periods of high volatility are followed by low volatility, a behaviour that is consistent with the extant literature (Charles and Darné, 2014). Volatility spikes are especially evident during the Gulf war and the global financial crisis, also found by Salisu and Fasanya (2013), where the returns of spot and futures oil prices show unsteady and more noticeable patterns than during the Asian crisis and the US terrorist attack (see figure 5.4 below).

Figure 5.4: Examples of Volatility Clustering



Source: Thompson Reuters Datastream and Eviews 8 (graphical adjustments added by the authors, 2016)

Table 5.2 below summarises the descriptive statistics for Brent spot and futures prices and their returns for the whole sample and all sub-samples. The mean for spot and futures prices shows a similar pattern for the whole period from December 1988 to December 2013, at approximately \$44.40 per day, the standard deviation (SD) is \$34.40 for spot prices and \$34.20 for futures prices per day, with skewness of about 1.04 and kurtosis at 2.7. We conclude that spot prices are slightly more volatile than futures prices, but the differences are quite insignificant, showing that both series seem to behave in a similar fashion. The mean return is close to 0.03, and the SD is 2.3 for spot and 2.2 percent for futures prices, skewness is 0.64 for spot prices and -1.30 for returns, and kurtosis is around 30 for both. This is an expected result and we can note that the standard deviation of Brent prices is high for both markets, where spot prices are slightly more volatile (measured by the SD) than futures prices. Brent returns are non-normal, showing evidence of negative skewness in most cases, and excess kurtosis, bearing out findings from prior research (Salisu and Fasanya, 2013). The Jarque-Bera test also confirms that the data series are non-normally distributed, this being a common finding for financial data (Vo, 2009). A close look at the returns for the identified shock periods and their sub-periods show quite interesting outcomes. During the Gulf war, the mean and SD of spot returns for the pre-crisis and post crisis periods are 0.13 and 0.015, and 2.24 and 1.42 percent respectively. The corresponding mean and SD of the futures returns are 0.21 and 0.01, and 2.2 and 1.44 respectively. Similar findings were noted by Charles and Darné (2014). However, the mean and SD during the crisis sub-period significantly differ from the results for stable periods. This has strong effects on investment decisions as the risks and fluctuations of oil prices during crises periods are excessive with increased potential of losses or gains. Table 1 shows that the mean of returns is negative for both spot and futures prices, where spot returns are -0.29 and futures returns are -0.57. Furthermore, the SD more than doubled to 4.79 and 5.98 for spot and futures returns

respectively. This result indicates that during the Gulf war period futures prices were characterised as being more volatile than spot returns.

During the Asian crisis period, the mean of spot and futures returns in the stable pre-crisis period is 0.09 for both, and for the post-crisis period is 0.17 and 0.13 respectively. The SD is similar for the pre-crisis period at around 1.9 and at 2.7 for the post-crisis period for both returns. The results for the crisis period are surprising, as they show a near to zero mean, but positive outcomes at 0.007 for spot and 0.005 for futures returns mean, and the SD at 2.50 for spot and 2.20 for futures returns. This shows that SD was slightly higher in the stable post-crisis period than during the crisis period. We would expect the opposite result, but this can be due to the fact that crisis period had a long duration (870 observations-days), which is the highest from all four shock periods, and it could smooth the effect of the SD fluctuations.

The US terrorist attack period showed a negative mean for the pre-crisis and crisis sub-periods for both spot and futures returns, whereas in the crisis period it showed results at -0.38 for both returns, and -0.01 for spot and -0.04 for futures in the pre-crisis period. This explains the decrease in spot and futures prices during this period. The SD showed an expected result when it reached the highest figures during the crisis period (3.20) compared to 2.00 during the stable period. The global financial crisis demonstrates similar patterns to the Gulf war period, where the mean is positive during the pre-crisis and post-crisis period for both returns and negative for the crisis period. The SD increased during the crisis period from 2 to over 3, and then again decreased to a level of 1.8.

From the above results we can conclude that the highest impact on SD fluctuations was registered during the Gulf war period, then during the US terrorist attack and the global

financial crisis and finally the lowest impact was during the Asian crisis. The same outcomes were found by Charles and Darné (2014) with larger fluctuations during the Gulf war than during the global financial crisis, which suggests that uncertainty is higher during war periods. The high impact of the US terrorist attack could be caused by global fears regarding air travel, which is directly connected with the oil markets than the result for the Asian crisis, which can be due to the fact that it had more of a regional effect than the other crises, limiting the magnitude of the transfer of the shock to the oil market. These findings are important in analysing the triggers and impact of each crisis on oil prices for volatility forecasting.

Table 5.2 Descriptive Statistics of Returns

		No. of Observations	Mean		SD		Skewness		Kurtosis		JB		
		Spot and Futures	Spot	Futures	Spot	Futures	Spot	Futures	Spot	Futures	Spot	Futures	
RETURNS	7/12/1988 to 31/12/2013	Brent Prices	6,540	44.3932	44.4274	34.3946	34.261	1.0508	1.0341	2.7094	2.672	1,,226.51	1,194.88
		Brent Returns	6,539	0.0312	0.0315	2.2637	2.1978	0.6393	-1.335	33.6616	28.7053	256,593	181,973
		The Gulf war											
		Whole Period	1,917	0.0226	0.0226	2.0484	2.2469	3.2954	-3.8171	138.538	76.4948	1,470,809	436,099
		Pre-crisis	471	0.1307	0.2134	2.2388	2.1614	7.3868	0.2494	92.0314	9.6547	159,843	873.982
		Crisis	132	-0.288	-0.5683	4.787	5.9822	1.402	-2.7202	50.0909	20.4688	12,239.8	1,841.15
		Post-crisis	1,314	0.015	0.0135	1.4243	1.441	-0.6939	-0.2493	32.0536	6.3976	46,320.5	645.631
		The Asian crisis											
		Whole Period	1,331	0.04279	0.039	2.3814	2.1586	0.2249	-0.164	6.409	6.2999	655.716	609.406
		Pre-crisis	337	0.0868	0.0904	1.9278	1.8196	0.2077	-0.7419	6.0387	8.8528	132.076	511.914
		Crisis	870	0.007	0.0052	2.4927	2.1942	0.387	0.1317	6.5202	5.7488	470.914	276.407
		Post-crisis	123	0.1737	0.1371	2.7016	2.7052	-0.6679	-0.7939	4.4749	5.3344	20.2931	40.8489
		US terrorist attack, 2001											
		Whole Period	653	-0.0191	-0.0055	2.7327	2.3598	-0.7029	-0.4611	8.3916	5.9821	844.698	265.113
		Pre-crisis	263	-0.011	-0.0375	2.598	2.3683	0.2757	-0.1259	4.3838	4.1014	24.3158	13.9893
		Crisis	105	-0.3819	-0.3813	3.9548	3.2206	-0.9397	-0.8052	7.044	5.9222	87	48.7042
		Post-crisis	284	0.1593	0.1752	2.0887	1.923	-0.1321	0.0536	3.3799	4.118	2.5342	14.926
		The Global Financial crisis											
		Whole Period	2,870	0.0453	0.0471	2.1853	2.09	0.0027	-0.1237	8.2726	6.2495	3324.43	1,270.04
		Pre-crisis	1,214	0.0699	0.0742	2.2106	1.9586	-0.0391	-0.0607	5.1425	3.8109	232.504	34.0095
		Crisis	371	-0.1335	-0.1218	3.1338	3.1692	0.1237	-0.0984	8.9883	5.0873	555.273	67.9454
		Post-crisis	1,284	0.07367	0.0704	1.7932	1.7986	0.0471	-0.0417	5.4765	6.2071	328.583	550.661

Note: SD is the daily standard deviation. JB is the Jarque and Berra (1980) statistics test for the null hypothesis of a Gaussian distribution.

The VAR lag structure outcomes using the Schwarz criterion are shown in Table 5.3 of Appendix C. It is used for selecting the appropriate number of lags for each variable in order to have the regressions correctly specified and avoid bias in the model specifications. The ADF test shows that spot and futures prices are non-stationary (have a unit root) in levels (Ozdemir et al., 2013), but are stationary in returns at 99 percent significance level for all four periods and their sub-periods (see Table 5.4). This is in contrast with Lee and Strazicich (2003) who argue that when structural breaks are incorporated, the results of stationarity analysis may change.

Table 5.4 Augmented Dickey-Fuller Test

	Spot Returns	Futures Returns	Spot Prices	Futures Prices
The Gulf war				
Whole Period	-44.0496***	-18.1148***	-0.1990	-0.0481
Pre-crisis	-21.6564***	-19.7107***	1.1149	2.3904**
Crisis	-16.0245***	-11.3635***	-2.1632**	-1.5591
Post-crisis	-36.9623***	-23.6133***	0.4667	0.1933
The Asian crisis				
Whole Period	-35.3969***	-37.1223***	0.6356	0.5715
Pre-crisis	-18.6631***	-18.0810***	0.7857	0.9534
Crisis	-28.2586***	-30.1144***	-0.1658	-0.2008
Post-crisis	-10.8031***	-11.5214***	0.5149	0.3491
US terrorist attack, 2001				
Whole Period	-27.1069***	-26.3991***	-0.2799	-0.2979
Pre-crisis	-14.8212***	-16.2174***	-0.3007	-0.5066
Crisis	-10.9737***	-10.0345***	-1.2749	-1.6549*
Post-crisis	-18.6359***	-19.8510***	1.2825	1.1491
The Global Financial crisis				
Whole Period	-54.9364***	-56.9026***	0.3687	0.3766
Pre-crisis	-37.4291***	-37.0698***	0.6837	0.8974
Crisis	-18.9997***	-21.0611***	-0.6094	-0.5923
Post-crisis	-35.5018***	-36.9526***	0.6789	0.6545

Note: ***, **, * represent statistical significance at 99%, 95% and 90% level respectively. All volatility models use returns for the analysis, even though in a few cases the series are stationary in levels. This is due to a fact that the estimations can be done with variables in the same level of integration, I(1) in our case.

The outcomes of Bai-Perron structural breakpoint test identified abnormal changes during all four crises periods and their sub-periods, which are shown in Table 5.5 in Appendix D. These dates are considered as the breakpoints and implemented in all testing.

5.5.2 Volatility Findings

The research findings are presented by comparative analysis among the four periods and their sub-periods, which is adding value to the existing literature by contrasting direct and indirect shocks to the oil market. Starting with the outcomes of the GARCH (1,1) model it continues with the analysis of T-GARCH (1,1) and the OLS models. The outcomes of the GARCH (1,1) (see Tables 5.6, 5.7, 5.8 and 5.9) present significant results. The Gulf war period shows positive and significant levels during the whole period of the Gulf war and also for the post-crisis period, both for futures returns. However, this was not the case for spot returns. Higher volatility spikes were found for the whole period ($\alpha=0.115$ versus $\alpha=0.051$ during the post-crisis sub-period), but longer persistence ($\beta=0.938$ compared to $\beta=0.874$) was the main feature during the post-crisis period. The outcomes for the Asian crisis are significant during the whole period for both returns, and for futures returns during the crisis sub-period. Higher volatility spikes are apparent for futures returns in the crisis sub-period compared to the whole period, where $\alpha=0.048$ ($\beta=0.90$) in the crisis period and $\alpha=0.039$ ($\beta=0.95$) during the whole period. We note that the Gulf war period had higher impact on volatility spikes than the Asian crisis. This indicates that the Iraq-Kuwait war compressed the oil market by oil supply uncertainty more than the regional Asian financial crisis.

The GARCH (1,1) model shows significant outcomes during the whole period for spot returns during the September 11 terrorist attack, where $\alpha=0.11$ and $\beta=0.81$. The terrorist

attack had an immediate impact on the oil market; however it had lower persistency than other shock periods under analysis. The outcomes for the global financial crisis are significant and positive for the whole period, pre-crisis and post-crisis sub-periods, including spot and futures returns. The futures returns indicate lower volatility spikes than spot returns during the pre-crisis ($\alpha=0.042$ versus $\alpha=0.057$ for spot returns) and post-crisis ($\alpha=0.051$ versus $\alpha=0.054$) sub-periods. Conversely, it is the opposite for the whole period ($\alpha=0.041$ for spot and $\alpha=0.046$ for futures). This indicates that in relatively stable periods, the spot returns appear to reach greater volatility highs than futures returns. This would mean that futures returns show slightly lower levels of risk than spot returns based on these outcomes. Volatility persistence is close to 1 in all cases, suggesting the existence of a slow mean reversion process. This outcome of high volatility persistence in Brent crude oil is consistent with the findings of Salisu and Fasanya (2013) who point towards more variations of spot prices in the Brent trends.

Table 5.6 and 5.7 Volatility Models for the Gulf war and the Asian Crisis

Table 5										Table 6									
The Gulf war										The Asian crisis									
		Whole Period		Pre-crisis		Crisis		Post-crisis				Whole Period		Pre-crisis		Crisis		Post-crisis	
		Spot	Futures	Spot	Futures	Spot	Futures	Spot	Futures			Spot	Futures	Spot	Futures	Spot	Futures	Spot	Futures
GARCH (1,1)	ω	2.685717*	0.068058***	2.759035	0.230545	10.94707*	10.44748**	0.228318*	0.025971**	GARCH (1,1)	ω	0.126431*	0.024865*	0.214763	0.035867	0.055276	0.222065***	0.730962	5.662002**
		(0.0854)	(0.0061)	(0.1385)	(0.2552)	(0.0621)	(0.0171)	(0.0588)	(0.0723)			(0.0595)	(0.0722)	(0.3037)	(0.2700)	(0.2371)	(0.0068)	(0.5579)	(0.0474)
	α	-0.004448	0.115114***	-0.007990	0.163385**	-0.018972	0.988638	-0.013032	0.051996***		α	0.059856**	0.039318***	0.078380	0.079045*	0.037656	0.048016**	0.090068	0.160091
		(0.0000)	(0.0000)	(0.0027)	(0.0213)	(0.0230)	(0.1512)	(0.0000)	(0.0001)			(0.0155)	(0.0031)	(0.2873)	(0.0637)	(0.1553)	(0.0120)	(0.5537)	(0.4423)
TGARCH (1,1)	β	0.593698**	0.874241***	0.612514*	0.797026***	0.443427**	0.152200*	0.910999***	0.938417***	TGARCH (1,1)	β	0.919669***	0.958119***	0.865887***	0.916409***	0.954253***	0.904362***	0.814844***	0.067463
		(0.0404)	(0.0000)	(0.0942)	(0.0000)	(0.0160)	(0.0952)	(0.0000)	(0.0000)			(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0044)	(0.8444)
	ω	2.711013***	0.064940***	3.277757***	0.258849	12.42255*	6.204024	1.273200***	0.028523*		ω	0.125915*	0.030331*	0.220929	0.033696	0.024723	0.221232***	9.234323***	0.347743
		(0.0007)	(0.0027)	(0.0101)	(0.2206)	(0.0717)	(0.1556)	(0.0062)	(0.0679)			(0.0650)	(0.0520)	(0.3323)	(0.2507)	(0.5409)	(0.0077)	(0.0000)	(0.1219)
OLS	α	0.049063*	0.146524***	0.018751	0.216826**	0.046494	0.780474	0.041121	0.066268**	OLS	α	0.054856*	0.062089**	0.073199	0.110302	0.012288	0.047859**	0.358679**	-0.108073
		(0.0685)	(0.0019)	(0.4066)	(0.0296)	(0.7363)	(0.3623)	(0.4064)	(0.0154)			(0.0717)	(0.0223)	(0.2469)	(0.1496)	(0.3999)	(0.0415)	(0.0429)	(0.0661)
	θ	-0.055429	-0.076372	-0.073971	-0.111954	-0.070787	-0.613526	-0.057496	-0.021080		θ	0.008840	-0.034261	0.012023	-0.069193	0.037199	0.000244	-0.321252	0.022265
		(0.0342)	(0.0987)	(0.0000)	(0.2799)	(0.6048)	(0.4857)	(0.2366)	(0.5043)			(0.7741)	(0.2516)	(0.9188)	(0.3406)	(0.1001)	(0.9932)	(0.0747)	(0.8395)
OLS	β	0.597446***	0.882176***	0.569648**	0.787199***	0.511583**	0.504887***	0.582952***	0.934232***	OLS	β	0.920285***	0.952373***	0.863263***	0.923011***	0.966803***	0.904575***	-0.516263	1.052632
		(0.0000)	(0.0000)	(0.0112)	(0.0000)	(0.0275)	(0.0021)	(0.0002)	(0.0000)			(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0342)	(0.0000)
	β	-0.005573		-0.010934		-0.010092	0.027884	0.014423			β	0.149571***		0.208165***	0.093726*	0.133840***		0.139510	0.117758
		(0.8075)	n/a	(0.8131)	n/a	(0.8433)	(0.7519)	(0.6052)	n/a			(0.0000)	n/a	(0.0001)	(0.0862)	(0.0001)	n/a	(0.1278)	(0.1994)
Note: ***, **, *represents statistical significance at 99%, 95% and 90% respectively. The OLS test was used to model volatility, in cases where there was no ARCH effect in the series and in samples below 500. n/a means 'not applied'.																			

Table 5.8 and 5.9 Volatility Models for the September 11 Terrorist attack and the Global Financial Crisis

Table 7										Table 8									
September 11, 2001										The Global Financial crisis									
		Whole Period		Pre-crisis		Crisis		Post-crisis				Whole Period		Pre-crisis		Crisis		Post-crisis	
		Spot	Futures	Spot	Futures	Spot	Futures	Spot	Futures			Spot	Futures	Spot	Futures	Spot	Futures	Spot	Futures
GARCH (1,1)	ω	0.505871**	0.125863	0.829830*	0.052835**	0.969741***	0.248427	0.151040	0.781431***	GARCH (1,1)	ω	0.015929**	0.027312***	0.496744*	0.163035*	-0.02092	0.037147	0.027236**	0.031424**
		(0.0159)	(0.1898)	(0.0623)	(0.0271)	(0.0001)	(0.2631)	(0.3454)	(0.0085)			(0.0471)	(0.0068)	(0.0698)	(0.0533)	(0.3990)	(0.3617)	(0.0476)	(0.0401)
	α	0.114163**	0.055947	0.050579	-0.046765	-0.176920	-0.111747	0.015556	0.016988		α	0.041174***	0.046749***	0.057131**	0.042366**	-0.016453	0.054246**	0.054135***	0.051398***
		(0.0155)	(0.1437)	(0.1676)	(0.0503)	(0.0000)	(0.0000)	(0.5449)	(0.7240)			(0.0000)	(0.0000)	(0.0437)	(0.0237)	(0.5584)	(0.0135)	(0.0000)	(0.0001)
TGARCH (1,1)	β	0.814289***	0.920731***	0.817358***	1.033265***	1.102183***	1.086053***	0.946683***	0.749102***	TGARCH (1,1)	β	0.955784***	0.946222***	0.839071***	0.913842***	1.031676***	0.948980***	0.935799***	0.937243***
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)			(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	ω	0.490875**	0.176263*	0.823876*	0.042317	1.215020*	0.576019	1.176413	0.705344***		ω	0.018071**	0.031328***	0.417378**	0.205849*	0.016366	0.057971**	0.022940*	0.038879**
		(0.0163)	(0.0945)	(0.0601)	(0.1213)	(0.0712)	(0.5642)	(0.3307)	(0.0077)			(0.0269)	(0.0042)	(0.0215)	(0.0527)	(0.6956)	(0.0170)	(0.0812)	(0.0345)
OLS	α	0.137856**	0.081322*	0.045631	-0.036820	-0.114559	0.206432	0.058554	0.042608	OLS	α	0.012962	0.028038**	-0.031023	0.007808	-0.031702	-0.062771	0.029421	0.028367
		(0.0281)	(0.0984)	(0.4310)	(0.2011)	(0.0241)	(0.2188)	(0.4724)	(0.5286)			(0.1473)	(0.0128)	(0.1376)	(0.7329)	(0.2516)	(0.0019)	(0.1253)	(0.1630)
	θ	-0.052413	-0.023259	0.009683	0.024491	-0.015997	-0.239756	-0.005007	-0.050988		θ	0.048651***	0.035929**	0.122909***	0.054882*	0.031114	0.077435***	0.040897*	0.059304**
		(0.3767)	(0.5309)	(0.8972)	(0.3708)	(0.8205)	(0.1084)	(0.9596)	(0.4678)			(0.0004)	(0.0105)	(0.0006)	(0.0684)	(0.2156)	(0.0011)	(0.0542)	(0.0156)
OLS	β	0.819902***	0.899254***	0.818149***	1.012381***	1.023686***	0.873194***	0.669310**	0.771723***	OLS	β	0.958722***	0.945511***	0.880699***	0.908929***	1.024011***	1.023271***	0.941404***	0.928476***
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0209)	(0.0000)			(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
	β		0.071944*	-0.067938	0.128281**	-0.032746	-0.021438	0.072062	0.085356*		β			0.140674***	0.127649**	0.121026**		0.097164***	
		n/a	(0.0666)	(0.3314)	(0.0390)	(0.7344)	(0.8290)	(0.2491)	(0.0829)			n/a	n/a	n/a	(0.0000)	(0.0140)	(0.0199)	n/a	(0.0005)
Note: ***, **, *represents statistical significance at 99%, 95% and 90% respectively. The OLS test was used to model volatility, not the returns, in cases where there was no ARCH effect in the series and in samples below 500. n/a means 'not applied'.										Note: ***, **, *represents statistical significance at 99%, 95% and 90% respectively. The OLS test was used to model volatility, not the returns, in cases where there was no ARCH effect in the series and in samples below 500. n/a means 'not applied'.									

During the Gulf war the T-GARCH model did not show any significant leverage effect in any of the sub-periods. However, it showed positive and significant results for ω , α and β during the whole Gulf war period for spot and futures returns and for futures returns during the post-crisis period. The outcomes of these coefficients are very close to the results of the GARCH (1,1) model, which suggests that T-GARCH method failed to model the series during this period. On the other hand, the GARCH model performed better in volatility analysis. The T-GARCH (1,1) model for the Asian crisis does not confirm the existence of asymmetries in our series, but shows nearly similar results for ω , α and β coefficients as in the GARCH model for the same sub-periods. If we look at the volatility persistence, we note that it was lower during the Gulf war ($\alpha+\beta\approx 0.98$), than during the Asian crisis ($\alpha+\beta\approx 0.99$). Nonetheless, the outcomes are very close indicating similarities in their behaviour.

On the other hand, during September 11, 2001 the GARCH (1,1) model shows significant outcomes during the whole period for spot returns, which also confirms the T-GARCH model findings. However, the T-GARCH method does not show any evidence of leverage effects. The T-GARCH (1,1) approach is significant and positive for the global financial crisis in the case of futures returns during the whole period indicating the existence of leverage effects. This finding suggests that negative news has a greater impact on volatility of oil than good news, which is consistent with findings of Wang and Wu (2012), and Salisu and Fasanya (2013).

With help of the OLS volatility model, we found that during the Gulf war period the model did not offer any significant results. However, the Asian crisis period shows significant results during the whole period for spot returns and the pre-crisis period for spot and futures returns, and also in the crisis sub-period for spot returns. The spot returns are more

predictable based on the past volatilities, which is indicated by higher coefficients above 0.13 for spot returns compared to 0.09 for futures.

Table 5.8 offers the results for the 2001 US terrorist attack. The OLS results are significant for futures returns for the whole period, pre-crisis and post-crisis sub-periods. The coefficient is the highest for the pre-crisis sub-period at 0.13 in comparison to the whole period at 0.07 and the post-crisis sub-period at 0.09.

In Table 5.9 the OLS test shows significant results, where it was applied, for all sub-periods during the global financial crisis. It is the only shock period, where this test demonstrates that in each case present volatility can be predicted by past volatility. It also indicates that the best forecasts are found for futures returns during the pre-crisis sub-period (0.14), than for spot and futures returns during the crisis sub-period (0.12). The coefficient for the post-crisis sub-period is slightly below the previous results at 0.10. This can be explained by the change in expectations in the oil market after the crisis, as the market is getting more stable than during the crisis turmoil of oil price swings up and down.

To summarise the main research findings the following points can be made. The GARCH (1,1) model provided some useful information on volatility spikes and volatility persistence, where there was evidence of higher persistency during the Asian and global financial crisis. On the other hand, the asymmetric T-GARCH (1,1) model, which has the ability to identify whether negative shocks have a larger effect on volatility than positive shocks, showed that in the case of the global financial crisis the results are significant for futures returns of the whole sample. No other asymmetric effects were significant. Overall, the GARCH (1,1) model worked better to capture volatility behaviour during the crises periods, which is consistent

with the research conducted by Charles and Darné (2014). Salisu and Fasanya (2013) also found the GARCH (1,1) model as a good volatility predictor for oil markets. Similarly, their finding showed that the EGARCH (1,1) model seems to offer a better fit over the T-GARCH (1,1) so as to capture any asymmetries in the series.

The OLS volatility test, which was applied only where GARCH (1,1) and T-GARCH (1,1) models did not fit or where the sub-sample was too small, showed that past volatility has a significant explanatory power in cases of the Asian crisis and the global financial crisis and for futures returns during the 2001 US terrorist attack. However, this test only showed volatility behaviour during the crises, but did not offer further conclusions.

A high level of volatility was found during all four shock periods. The biggest impact was identified during the Gulf war crisis sub period, which can be explained by the direct disruption of oil supply and reflects the market behaviour during the war. This had an impact on all oil market participants due to high level of uncertainty in respect of futures oil prices. Salisu and Fasanya (2013) and Foster (1996) examined the volatility of Brent crude oil prices during the Gulf war and also identified that the highest volatility occurred during the crisis period caused by higher uncertainty in supply/demand activities, which gives rise to higher risks associated with oil prices.

All four shock periods under analysis show significant evidence of price changes and high volatility, as shown in Appendix A and B, where the Gulf war and the US terrorist attack in 2001 indicated the highest volatility spikes. The Brent oil market is characterised as being volatile with the occurrence of large shocks, which are due to economic, political or financial causes. The GARCH (1,1) model shows higher spikes and lower persistence during direct oil

supply/demand shocks such as the Gulf war and the US terrorist attack in 2001. The economic or financial shocks during the Asian crisis and the global financial crisis have higher persistence and lower volatility spikes, meaning that uncertainty and risk in the oil market last longer. Negative shocks mainly affect oil prices dynamics by increasing the risk and levels of uncertainty in the market. The T-GARCH (1,1) model confirmed that during the global financial crisis, negative news affected oil prices more than good news. This is consistent with the research conducted by Wei et al. (2010), Wang and Wu (2012) and Salisu and Fasanya (2013).

5.6 Critical Discussion

The volatility models proposed in this research are based on previous research in the oil field (Oberndorfer, 2009; Wang and Wu, 2012; Salisu and Fasanya, 2013; Charles and Darné, 2014; Wang et al., 2016). The proposed models did not fit our series in all cases due to the existence of heteroskedasticity and serial correlation issues¹⁸. The OLS model was included as an alternative to test oil volatility where GARCH (1,1) and T-GARCH (1,1) failed. We did not find the OLS test an optimal volatility indicator as it is limited in answering our research questions. On the other hand, the GARCH (1,1) method offered the best estimates (as also in the findings of Salisu and Fasanya (2013)). In case of asymmetric effects, the T-GARCH (1,1) model did not add useful information as its outcomes were similar to the estimations of the GARCH (1,1) model, with the only exception being the findings during the global financial crisis period, where it identified a higher impact of bad news on oil volatility for futures returns of the whole and pre-crisis sub periods.

¹⁸ The outcomes of robustness tests are not included in this paper, but are available upon request.

A major contribution of this research is the simultaneous analysis of two direct oil crises (the Gulf war and the US terrorist attack) and two indirect crises (the Asian crisis and the global financial crisis). The uncertainty and risk in the oil market can be measured by the volatility changes during crises periods and persistence, which prolongs uncertainty in respect of oil prices (Hamilton, 2011; Wang and Wu, 2012; Ozdemir et al., 2013; Charles and Darné, 2014). The findings on persistence and behaviour during different shocks can help in deciding what investment approach to follow and how to minimise risk as an investor. Careful investment decisions or portfolio diversification during these periods might be prudent. In the cases of war and terrorist attacks, which directly impacted oil supply and demand, it showed lower volatility persistence, indicating shorter horizon changes of strategy than in cases of financial or economic crises, where the uncertainty impacts the oil market for extended periods. Our findings are consistent with other studies in this area such as Park and Ratti (2008) and Salisu and Fasanya (2013).

The innovation in this research is firstly the breaking of the series into relatively stable and crises sub periods with the help of structural breaks, and comparing the stable periods before and after the crises, which offers in depth analysis of oil behaviour. Mainly, we note that the stable periods before the crises are more predictable than the relatively stable periods after the crises, where the past volatilities during crisis sub periods shook the market. Secondly, we use symmetric and asymmetric volatility models for all sub periods to test for differences in the series behaviour in numerous shock periods. This offers extended volatility analysis, which simultaneously explores all four crises periods.

To recap our main hypothesis, we can conclude that oil volatility is affected by crises periods under this study in all cases, which indicates the significant importance of monitoring

political and financial events in relation to oil prices. This is consistent with other studies looking at oil prices during shock periods (Wang and Wu, 2012; Salisu and Fasanya, 2013). We also identified different levels of volatility persistence during different crises, which demonstrates that the origins of crises affect the persistence (Charles and Darné, 2014). Furthermore, with the help of the asymmetric T-GARCH (1,1) model we found that negative news has a bigger impact than good news during some sub periods for the global financial crisis. Wei et al. (2010) and Wang and Wu (2012) discovered in their research that asymmetric GARCH type models were good oil volatility predictors, which motivates us to include other asymmetric models in future research.

5.7 Conclusions

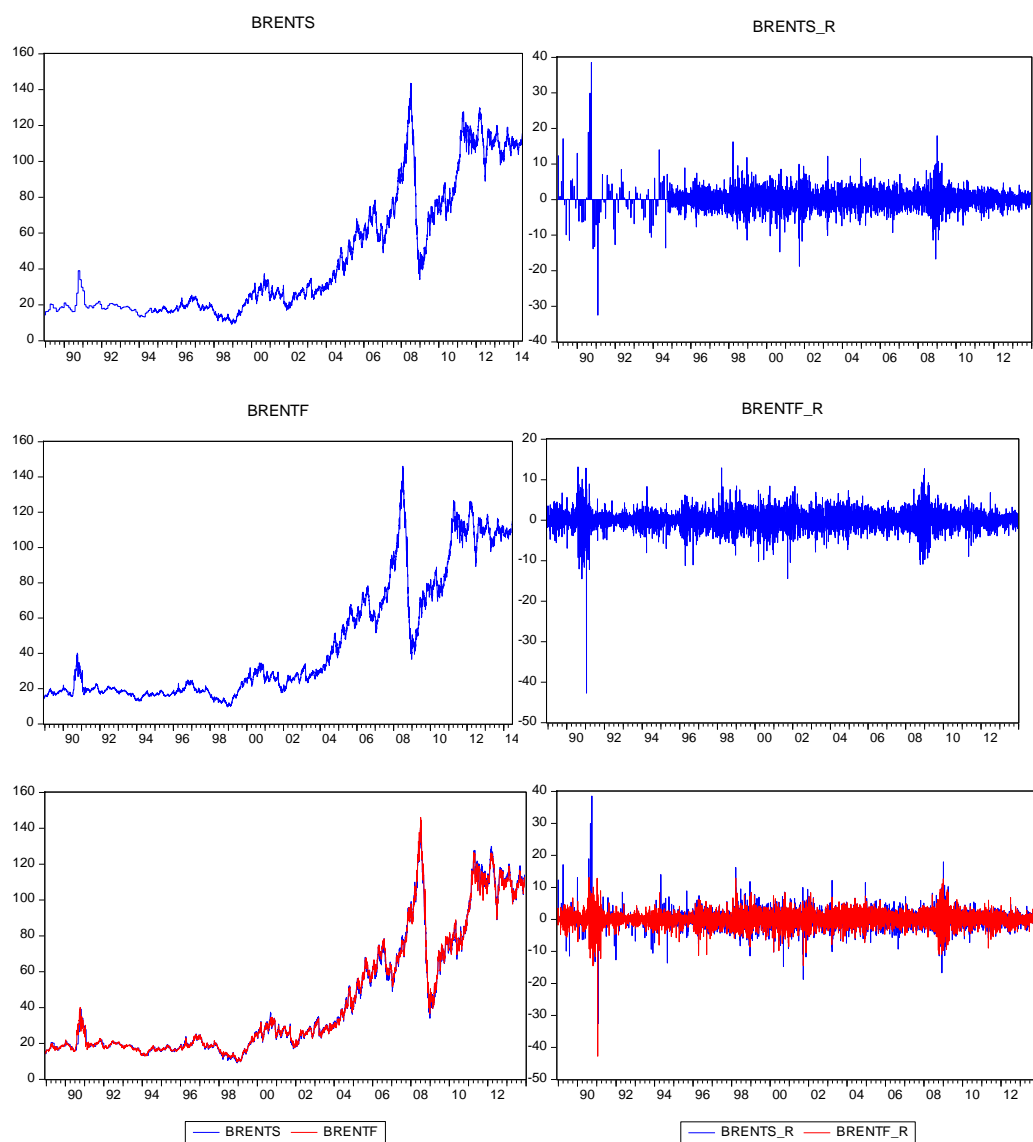
The Gulf war, the Asian crisis, the US terrorist attack and the global financial crisis were analysed in this study. Findings show significant evidence of shocks being transferred to the oil market during times of economic and financial turbulence. The risks involved with high oil volatility influence the decision making process of investors, speculators and policy makers, all of whom are market participants who need to have a good understanding of oil markets volatility patterns. GARCH (1,1), T-GARCH (1,1) and the OLS regression models were run to test oil volatility, finding that during times of direct oil supply/demand disruptions - such as the ones that took place during the Gulf war and 2001 US terrorist attack period - the series exhibited higher volatility spikes ($\alpha \approx 0.12$ and 0.11 respectively versus 0.04), but lower volatility persistence compared to the behaviour during the Asian and the global financial crisis ($\alpha + \beta \approx 0.99$ for both versus 0.92) that were considered to have an indirect impact on the oil market. In the case of the global financial crisis futures returns,

using the asymmetric T-GARCH (1,1) model, were found to be influenced by negative news that has a greater effect on oil price volatility than good news, a research finding that is consistent with Wei et al. (2010), Wang and Wu (2012) and Salisu and Fasanya (2013). In those cases, where the results were found to be significant, the stable periods before and after the crises indicated a drop in volatility. Nonetheless, in all cases volatility levels increased during all four shock periods. Our findings of volatility models of crude oil spot and futures prices in stable and crises periods could influence the decisions of investors in oil markets and affect policy/investment decision making by governments. As both markets are affected by shocks and uncertainty, oil market participants should not base future spot prices on current futures prices but rather base decisions on current spot prices performance. Investors, policymakers and oil market participants should take into account the nature of the crises periods and look at the behaviour of oil spot and futures prices during certain periods, where longer uncertainty is found when economic and financial distress occurs, which is difficult for long run decision making, and higher volatility swings are found during supply/demand shocks, for both prices.

The inclusion of additional asymmetric models might be helpful to discover further asymmetries in the oil market. For example, Charles and Darné (2014) pointed out that the IGARCH model seems to better capture asymmetries for Brent crude series, and Salisu and Fasanya (2013) found the EGARCH model to fit best oil returns. Therefore, further research in the field should consider the implementation of additional GARCH type models with non-negative conditions, such as EGARCH or IGARCH that would help understanding if the GARCH(1,1) approach is the most efficient model to understand oil price dynamics.

Appendix

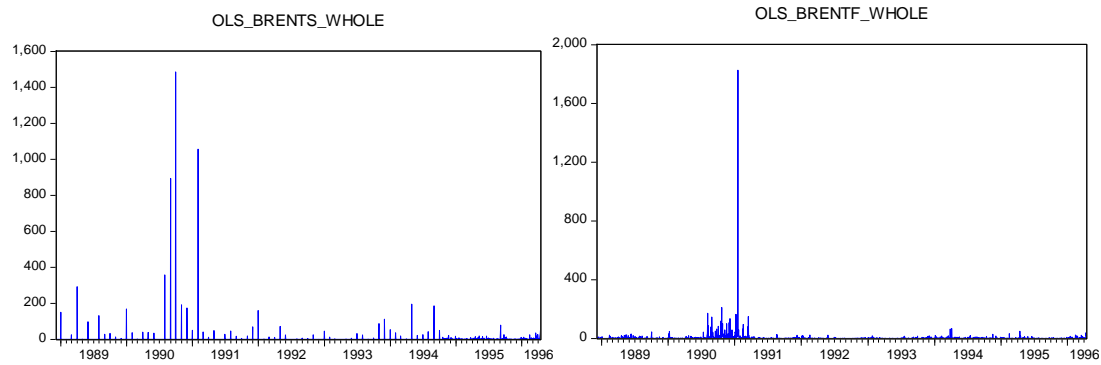
A. Historical Brent Spot and Futures Prices/Returns Dec 1988 to Dec 2013



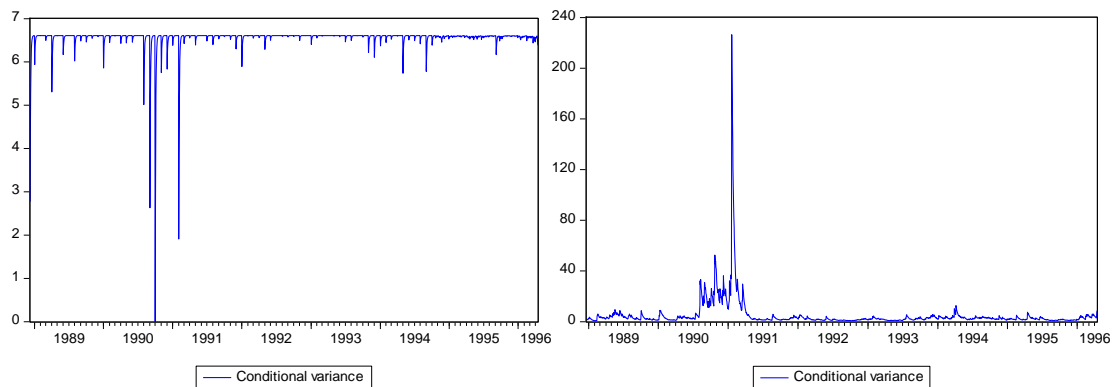
B. Volatility Graphs

B.1 The Gulf war

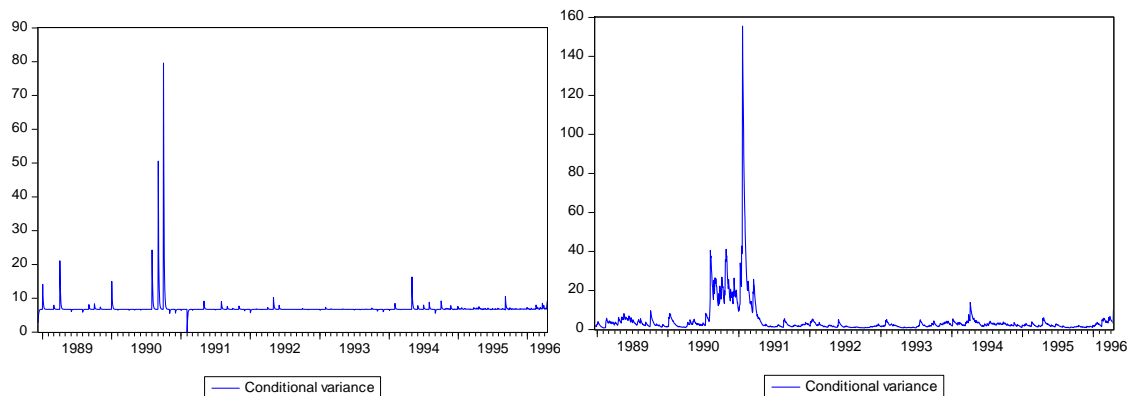
OLS: Brent Spot Whole/Brent Futures Whole



GARCH: Brent Spot Whole/Brent Futures Whole

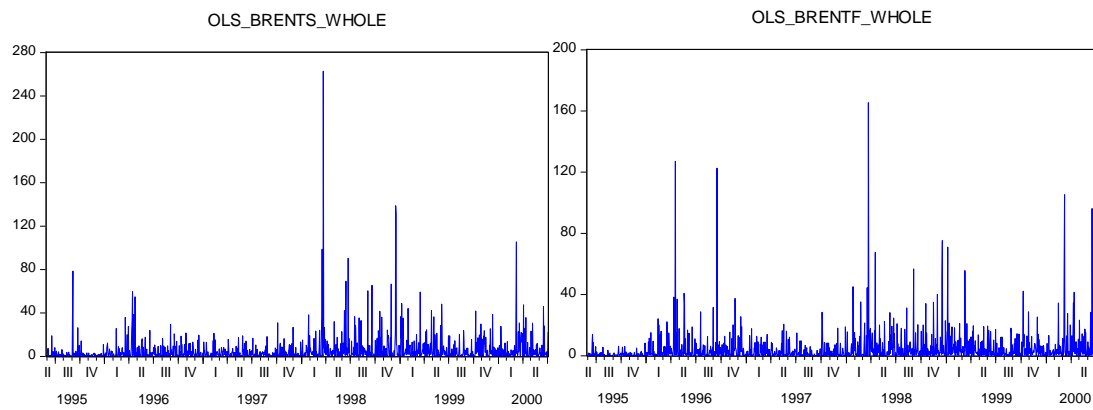


TGARCH: Brent Spot Whole/Brent Futures Whole

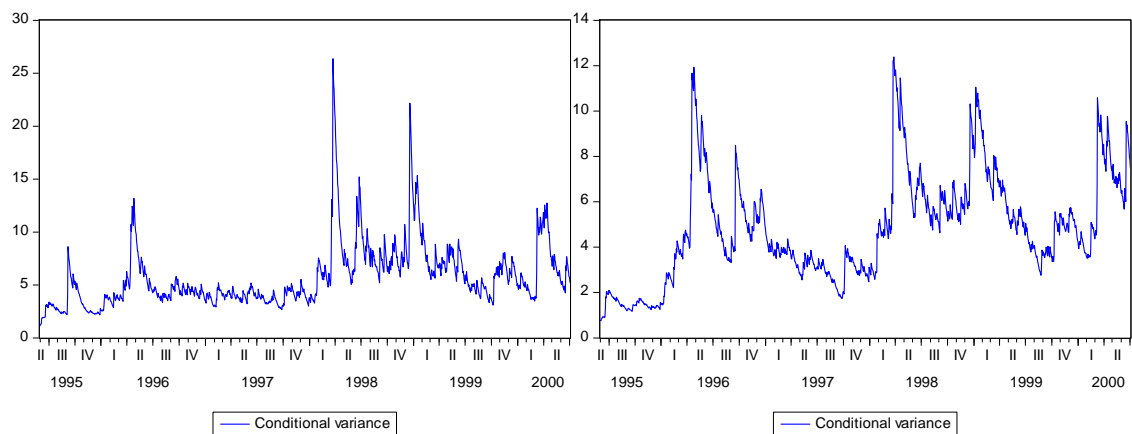


B.2 The Asian Financial Crisis

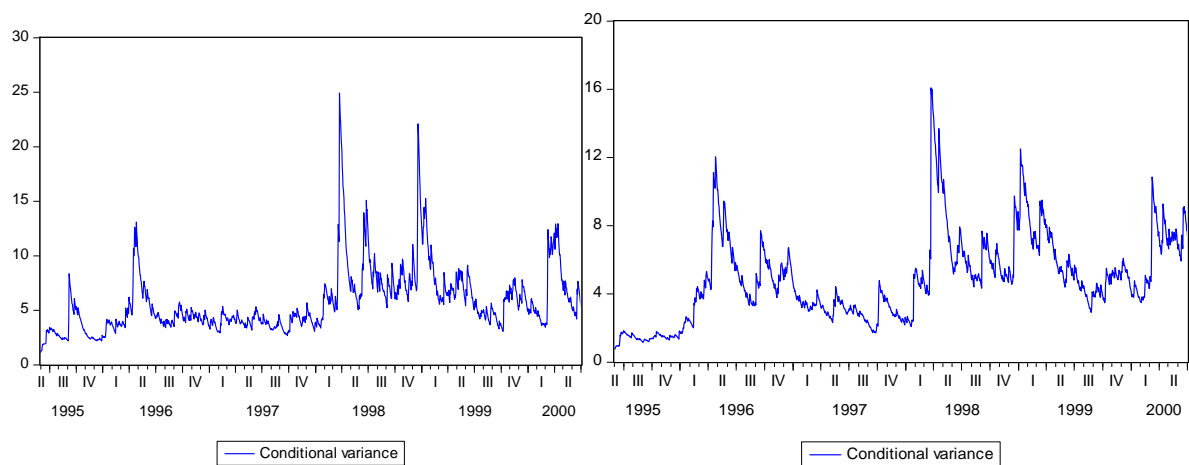
OLS: Brent Spot Whole/Brent Futures Whole



GARCH: Brent Spot Whole/Brent Futures Whole

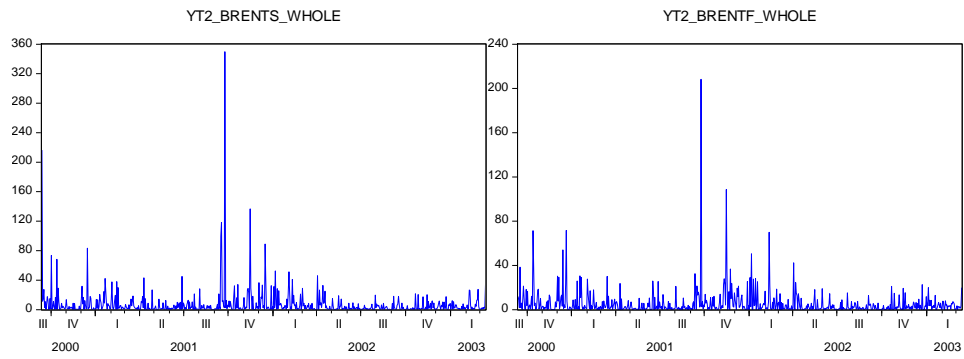


TGARCH: Brent Spot Whole/Brent Futures Whole

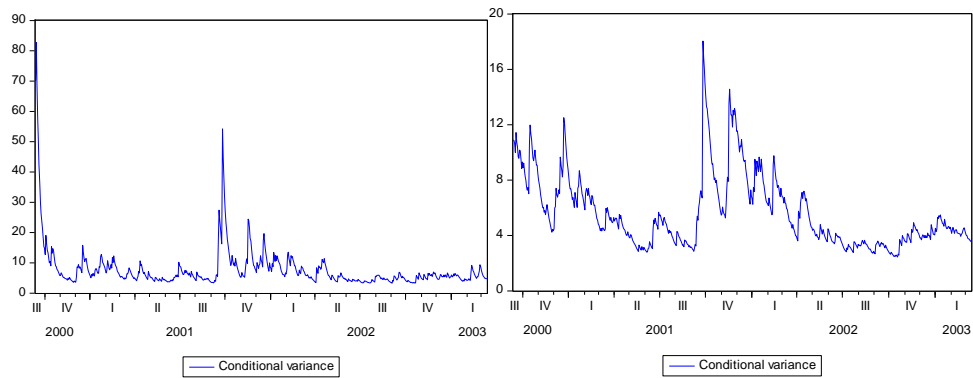


B.3 US terrorist attack, 2001

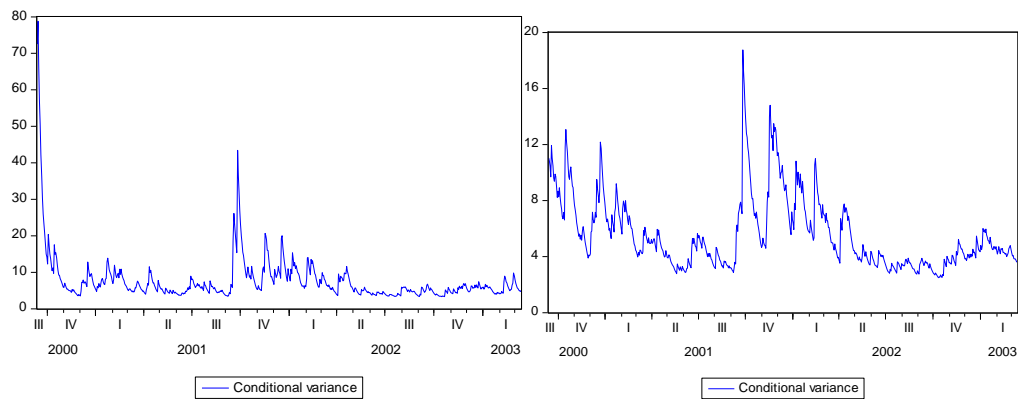
OLS: Brent Spot Whole/Brent Futures Whole



GARCH: Brent Spot Whole/Brent Futures Whole

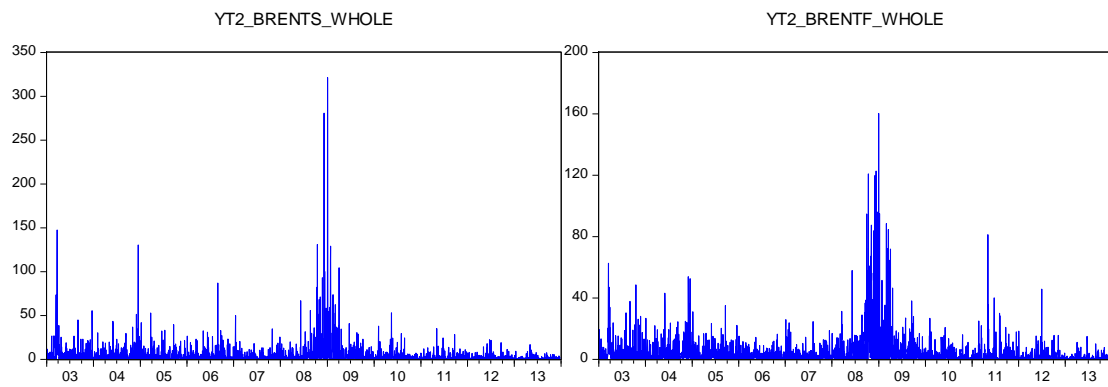


TGARCH: Brent Spot Whole/Brent Futures Whole

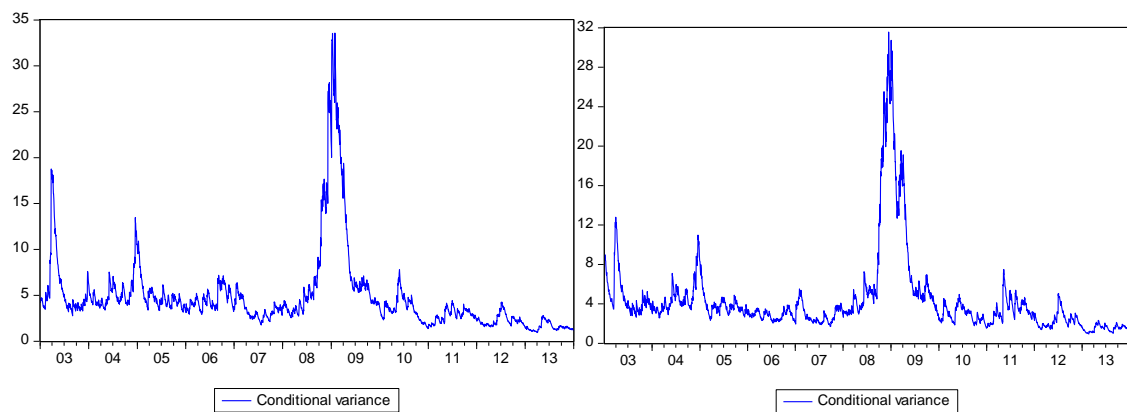


B.4 The GFC

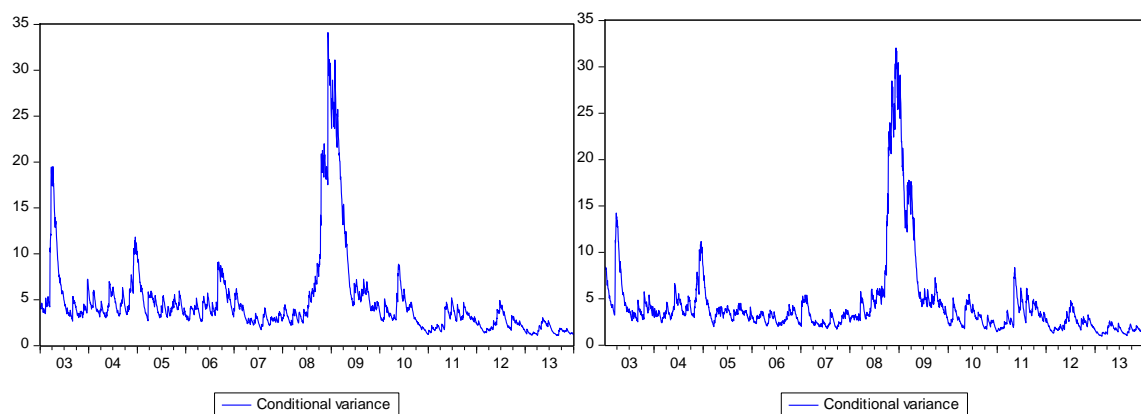
OLS: Brent Spot Whole/Brent Futures Whole



GARCH: Brent Spot Whole/Brent Futures Whole



TGARCH: Brent Spot Whole/Brent Futures Whole



C. VAR Lag Length

Table 5.3: Lag Structure using Schwarz Criterion

	Single Var Lag Length using Log Returns		Combined Var Lag Length using Prices in Level
	Spot	Futures	
The Gulf war			
Whole Period	0	8	11
Pre-crisis	0	0	
Crisis	0	0	
Post-crisis	0	0	
The Asian crisis			
Whole Period	0	0	2
Pre-crisis	0	0	
Crisis	0	0	
Post-crisis	0	0	
US terrorist attack, 2001			
Whole Period	0	0	2
Pre-crisis	0	0	
Crisis	0	0	
Post-crisis	0	0	
The Global Financial crisis			
Whole Period	0	1	4
Pre-crisis	0	0	
Crisis	0	0	
Post-crisis	0	0	

D. Bai-Perron Structural Break Points

Table 5.5: Structural Break Points- Bai-Perron Test

The Gulf war	
Whole Period	7/12/1988 to 12/04/1996
Pre-crisis	7/12/1988 to 27/09/1990
Crisis	28/09/1990 to 1/04/1991
Post-crisis	2/04/1991 to 12/04/1996
The Asian crisis	
Whole Period	30/05/1995 to 4/07/2000
Pre-crisis	30/05/1995 to 12/09/1996
Crisis	13/09/1996 to 13/01/2000
Post-crisis	14/01/2000 to 4/07/2000
US terrorist attack, 2001	
Whole Period	12/09/2000 to 13/03/2003
Pre-crisis	12/09/2000 to 16/09/2001
Crisis	17/09/2001 to 8/02/2002
Post-crisis	9/02/2002 to 13/03/2003
The Global Financial crisis	
Whole Period	1/01/2003 to 31/12/2013
Pre-crisis	1/01/2003 to 28/08/2007
Crisis	29/08/2007 to 28/01/2009
Post-crisis	29/01/2009 to 31/12/2013

Chapter 6 - Paper 3

Efficiency Analysis of Crude Oil Spot and Futures Prices¹⁹

6.1 Abstract

This paper explores the efficiency of oil price behaviour during times of crisis using traditional variance-ratio tests in combination with more recent innovations such as wild bootstrapping and simulation methods. Three main oil indices were chosen: Brent, WTI and Dubai crude, in order to consider efficiency across the different oil price regimes during times of crisis. Daily data from January 1986 to September 2016 was used, and moving windows of 2, 5 and 10 years were integrated into the methodologies applied. The results were mixed across the data series and the windows showing that the different prices were not efficient over the same periods. This has implications for how we view price efficiency in oil markets and consequent implications for market regulations and investor decision making during times of crisis.

Keywords: Energy, Crude oil markets, Spot and Futures Prices, Variance Ratio tests, Market Efficiency.

¹⁹ This paper has been reformatted to fit with the DIT thesis presentation guidelines.

6.2 Introduction

Crude oil is the main energy resource worldwide, being the most consumed non-renewable energy commodity, and together with natural gas, coal and nuclear power, it accounts for around 86 percent of the world's energy consumption needs. Recent analyses from the US Energy Information Administration (EIA) suggests that oil will remain as a major energy resource for the years to come. This clearly requires a deeper understanding of oil price behaviour and its contextualisation in the efficiency debate. An analysis of the extant literature shows significant controversies when trying to identify if oil markets are efficient or not. The contribution of this paper to the debate is to consider both short and long run behaviour through the use of rolling windows and also to use a combination of research methods, to better understand the efficiency phenomenon in oil prices.

Historically, crude oil prices have faced severe episodes of uncertainty that are mainly associated with situations of political unrest, economic and financial distress, OPEC decisions and natural disasters. These factors are identified as major contributors of market instability and substantiate some of the dramatic changes seen in the behaviour of oil prices. High levels of uncertainty have led to raising levels of volatility that are identified as a common feature of oil markets dynamics. Demand and supply levels play an important role in oil price levels, but increasing speculation in oil markets have been deemed as another important source of instability that are bringing further new dynamics to oil markets behaviour (Davidson, 2008; Kaufmann and Ullman, 2009; Kaufmann, 2011).

The analysis of oil prices and their reaction to market shocks in the context of market efficiency is the guiding point of this study. The use of different rolling windows was

considered as a suitable approach because it facilitates the identification of potential increases in oil prices volatility that differentiates between times of relative normality and times affected by remarkable instability. Increased oil price volatility and market instability could more clearly depict periods, where oil prices might be affected by increased speculation and irrational investment decisions. Therefore, the random walk hypothesis (RWH) under the weak form of market efficiency should not hold and oil markets may be expected to follow the propositions of the adaptive market hypothesis (AMH), a concept emanating from behavioural finance literature, which suggests that prices patterns are subject to predictions.

The unique contribution of this paper is the assessment of the efficiencies of three main crude oil benchmarks' spot and futures prices (Brent, Dubai and WTI crudes). Additionally, the study is supported by the use of multiple methods that combined with the moving window approach, help to offer a detailed and in depth analysis of the dynamics of oil prices. The existence of market efficiencies will suggest that the best predictor for future prices and returns should be based on current prices or current price returns, and that market behaviour will not be influenced by past prices. This assumption is framed under the discussion of the Efficient Market Hypothesis (EMH) proposed by Fama (1965). The random walk hypothesis is understood as the weak-form of the EMH, and its goal is to test if prices are predictable, in which case they will offer arbitrage opportunities, or whether markets follow a random walk and consequently they move in an arbitrary and unpredictable manner.

A close examination of existing studies looking at market efficiency and efficient market hypothesis shows a growing trend in the literature with regard to the behavioural finance stream. Robert Shiller, the 2013 Nobel Prize in Economics winner – claims that stock prices are inefficient and that they can be predicted over a long period of time. This concept was

first introduced by Kahneman and Tversky in the late 1960s and explains that in reality economic decisions follow psychological principles and not market fundamentals like in case of the EMH (Kahnema and Tversky, 1979). More recent studies argue that the behavioural finance theory is mostly linked to extreme market conditions and in particular to crises periods (Ciner et al., 2013). This view is in contrast to, for example, Dowling et al., (2016) who suggest that psychological barriers based on behavioural finance concepts are more evident in pre-crises periods. The outline findings from the literature vindicate the interest and relevance of this study, as the research context considers the analysis of oil prices behaviour over a long period of time to ensure that both times of normality and instability are properly examined, and that further evidence is gathered to contribute to the existing efficiency debate.

6.2.1 Research Questions and Main Motivation

Questions about the importance of being able to predict oil prices are continuously raised, and they affect the connection that exists between spot and future prices. The literature shows how spot and futures prices seem to influence each other, with interesting dynamics indicating that generally spot and future prices seem to influence each other in the long run, while futures prices may lead spot prices in the short run (Bekiros and Diks, 2008; Lee and Zeng, 2011; Zhang and Wang, 2013). As a result, the need to understand whether there is potential for market efficiencies affecting spot and futures oil markets is of significant importance. Thus, the outlined research questions and hypotheses consider the existence of market efficiencies and their dynamism.

a) Do Brent, WTI and Dubai crude oil spot/futures market follow a random walk hypothesis and satisfy the weak form of EMH?

b) Do Brent, WTI and Dubai crude oil market efficiency change over time?

The research hypotheses are:

H_0 : Returns of crude oil spot/futures prices exhibit random walk patterns and therefore satisfy the weak form of EMH.

H_A : Returns of crude oil spot/futures prices do not exhibit random walk patterns and therefore do not satisfy the weak form of EMH.

The main contribution of this study is the analysis of similarities and/or differences in the efficiencies of spot and futures prices by considering their dynamics over a long period of time. This enables consideration of how prices behave during times of relative market stability and shocks, and further analysis is conducted through analysing three global oil price benchmarks. Moreover, the methodological framework was carefully developed to ensure that traditional and well known methodologies in the efficiency field were integrated and combined with more up to date approaches, to allow the presentation of more robust outcomes, and the cross-validation of results.

The rest of the paper is organised as follows. Section 2 presents the research context by analysing core studies looking at oil futures and spot dynamics from the perspective of market efficiency. Section 3 discusses the data and the chosen research methodologies. Section 4 deals with the presentation and discussion of the main research outcomes, and finally, section 5 concludes the paper.

6.3 Literature Review

The efficiency of crude oil markets have been analysed and discussed by a significant number of researchers (Charles and Darné, 2009; Lean et al., 2010; Zhang, 2013; Khediri and Charfeddine, 2015; Gu and Zhang, 2016). The extant research has demonstrated how interlinkages between oil prices are important, as they significantly impact on the decision making process by businesses, investors, governments, financial analysts, economists and many other stakeholders that regularly interact with oil markets. The literature differentiates between two main theory streams: i) the well-known Efficient Market Hypothesis theory (Fama, 1965) and, ii) the behavioural finance theory stream (Lo, 2004); these streams that are considered in the discussions that follow.

6.3.1 The role of OPEC and Speculation

OPEC is a major player regarding oil price efficiency and could be seen as an oil price “manipulator”. Hamilton (2013) identified an initial period that he labelled as “The age of OPEC” from 1973 until 1996 and a second period that he named as “A new industrial age” that spans from 1997 until the present day. He argues that OPEC decisions about oil production could greatly influence its prices, and consequently, such interventions could be affecting oil price efficiency. Lin and Tamvakis (2010) and Barros et al. (2011), support this strong view. Lin and Tamvakis (2010) studied the impact of OPEC decisions on heavy and light crudes between 1982 and 2008. They found that the decisions influenced oil prices in terms of their specific context. For example, some OPEC meetings generated excessive interest among oil speculators, which ended up creating oil price fluctuations and increased levels of volatility. In the cases where decisions were not perceived to be relevant, oil prices

were not significantly affected. Decisions, speculation and hedging practices by OPEC have more recently been examined by Kaufmann (2011), who suggests that there is a need to consider factors other than OPECs' decisions influencing speculators and hedgers, such as, for example, the macro-economy, business cycles and natural disasters. In their research of stock market efficiency focusing on Asian countries, who tend to be heavily dependent on oil imports, Lim et al. (2008) suggested that wars, OPEC production cuts, natural disasters, terrorist attacks, and economic and financial crises could have an impact on price efficiency, as investors might overreact during chaotic times. These initial findings justify the need to look at market efficiency during times of instability, to help clarify if periods of low and high levels of efficiency could be linked to times of stability or if they are more connected to periods of remarkable uncertainty.

Barros et al. (2011) suggest that specific events may have an impact on oil prices, and that they are also conditioned by the kind of policies implemented by OPEC. Other authors, such as Loutia et al. (2016) consider that OPEC's decisions have several effects on oil prices. Firstly, they suggest that the impact of OPEC's decisions on oil prices is not static and it changes over time. Secondly, OPEC's influence is more significant in the areas of 'production cuts' and 'maintenance of production levels' rather than in decisions dealing with 'increasing levels of production', meaning that it is mainly driven by supply side information. Thirdly, they point out that the effect on Brent and WTI is not the same, which suggests that further analysis and studies should be developed to test for the existence of differences affecting these markets. Therefore, the importance of further efficiency analysis due to the various research findings that have been documented is identified as a key point in this study, where it has been considered that the inclusion of three main crude oil benchmarks (their spot and futures prices) will add extra information to the existing literature and current debate.

6.3.2 Common Methodologies Applied in the Existing Literature

Numerous studies have examined oil price efficiency (spot and/or futures prices) in different countries, using various methodologies, time periods and data frequencies. The findings offer a variety of conclusions with several outcomes, where in some instances EMH under random walk hypothesis holds and in other instances, the behavioural finance stream is considered as a better causative factor in predicting oil price behaviour. However, there seems to be a gap in the available literature, as the analysis of three of the world major oil benchmarks under the context of market efficiency, and specifically in the context of market crises, has not yet received sufficient attention.

For example, Charles and Darné (2009) analysed the efficiency of Brent and WTI crude oil daily spot prices between 1982 and 2008 using variance ratio tests to examine the random walk hypothesis. The outcomes showed that the Brent market is weak form efficient, while WTI seems to be inefficient between 1994 and 2008. These findings suggest that the market deregulation process that took place in 1994 did not improve the efficiency of the WTI crude oil market. Their findings are consistent with Serletis and Andreadis (2004), but in contrast with Tabak and Cajueiro (2007) who found the WTI oil market to be more efficient than Brent, using the rescaled range Hurts analysis between 1983 and 2004. Brent and WTI were also examined by Gu et al. (2010) using multifractal de-trended fluctuations between 1987 and 2008, finding that both markets became more efficient in the long run. In contrast, the findings from Wang and Wu's (2013) study, examining futures markets, suggest that oil futures markets are inefficient, and that such inefficiencies are more evident in the long run than in the short run. For this reason, this paper uses long (10 year), medium (5 year) and short (2 year) moving windows to be able to compare outcomes for spot and futures prices for

all three benchmarks, as the literature seems to suggest that futures prices might dominate spot prices at some point in time. Additionally, researchers seem to be looking at the behaviour of Brent and WTI prices as no other benchmarks seem to capture analysts' interest. Another aspect to take into account is how prices behave during times of distress. It seems that during times of crises or high instability, spot and futures prices appear to be following different trends than during periods of relatively stability.

Another issue that needs to be considered carefully is the type of data used to perform efficiency analysis. For example, Ozdemir et al. (2013) propose in their research that Brent spot and futures markets are weak form efficient. The authors used monthly data, which suggests that different data frequencies could lead to different results, and that care is needed when identifying if high or lower frequencies are going to be considered in the proposed study. In order to capture changes of oil price behaviour, the use of daily data seems more appropriate for this study, as the main goal is to capture changes during crises periods, where some of the events might be shorter than others, and important data might be lost if longer frequencies are used (Charles and Darné, 2009; Narayan et al., 2010).

Other researchers, such as Khediri and Charfeddine (2015) examined WTI daily spot and futures prices under a time-varying weak form efficiency framework. Their approach consists of wild bootstrapping variance ratio tests and the detrended fluctuation analysis (DFA) long memory parameters. The results show that market efficiency is not uniform over time, which is consistent with the adaptive market hypothesis (AMH) theory introduced by Andrew Lo in 2004. Lo (2004) suggests that investors and market-makers are not always rational in their decisions and that they react on the basis of a changing environment. These changes include overreaction or overconfidence based on behavioural biases, which clearly impact market

price behaviour when applied by multiple market players. This view is supported by behavioural finance theory as it can explain unexpected market movements, which are not based on supply/demand levels. These findings substantiate the need of considering research frameworks that integrate established models under EMH, but that also look at the application and implications of AMH.

Lean et al. (2010) noted that with increasing oil price fluctuations, oil futures became one of the most traded derivatives to hedge for price risks. In their analysis they used mean-variance and stochastic dominance approaches based on WTI data from 1989 to 2008. They also noted that speculation in oil futures stabilises the oil market, which is in contrast with some researchers views that have noted that speculation does not influence oil prices (Hamilton, 2009; Fattouh et al., 2013; Hamilton, 2014). Furthermore, Kim (2015) found that futures prices have a significant positive impact on past price changes, which could suggest that with the introduction of futures markets prices, efficiency should improve over time. Other authors examining the efficiency of oil markets are Jiang et al. (2014) who examined daily WTI futures prices from 1983 until 2012 using the Hurst indexes and bootstrapping techniques to verify the weak form market efficiency hypothesis. In their study the dataset was analysed as a whole, and they also split it into two and three sub-samples. They found that the WTI market over the whole period tested is efficient. When they split the sample into three sub-periods based on the Gulf war and Iraq war, it showed that the Gulf war reduced the efficiency of the market. When they split the sample into two sub-periods based on the North American Free Trade Agreement in 1994, the market was again found to be inefficient in the sub-period including the Gulf war. These results are interesting as they show evidence of changes in efficiency dynamics associated with times of increased instability, and also that

longer periods' results need to be taken with caution as they might be affected by changes of patterns on prices behaviour.

Gu and Zhang (2016) considered crude oil market efficiency and the impact of multifractality. The multifractality study included supply and demand levels, geopolitical events, natural disasters and economic activities. Furthermore, speculation is an important player in setting oil prices, as it can influence oil prices in two ways. Speculators can invest in the real market (spot market) by buying at low prices and selling at high or they can speculate in the futures market, which is more common. Therefore, analysing the efficiency of oil futures prices can offer important indicators for oil market participants, especially when comparing three major crude oil indexes.

Based on Behavioural Finance theory, Malkiel (2003) studied the psychological elements of business decisions. More closely, he looked at stock market efficiency and predictability and found that the EMH theory holds. He suggests that the cases of “bubbles” are the exception rather than the norm. Overall, his views suggest that the markets are efficient in most cases and abnormal behaviour seldom occurs. This is consistent with the research conducted by Sornette et al. (2009) who found support for the behavioural side of investment decisions during ‘bubble-like expansions’ between 2006 and 2008, which, they suggest, could be caused by rumours of rising scarcity, and that could lead to protective hedging against oil futures increases. Ellen and Zwinkels (2010) also suggest that switching between different forecasting strategies, which often depend on the profits of a prior strategy, could affect the decisions about oil prices taken during uncertain times.

Previous studies, which examined different time periods, offer useful information about crude oil markets (Tabak and Cajueiro, 2007; Charles and Darné, 2009; Jiang et al., 2014). They found that oil markets are non-stationary in levels, but stationary in returns, and that oil returns are heteroskedastic, which is important for further testing and at the same time confirm that oil prices behave according to the basic characteristics of time series variables. These findings contribute to settling the starting point of the methodology section, where multiple variance ratio tests, GARCH type methodologies and AMH concepts are chosen to analyse spot and futures prices efficiency over time.

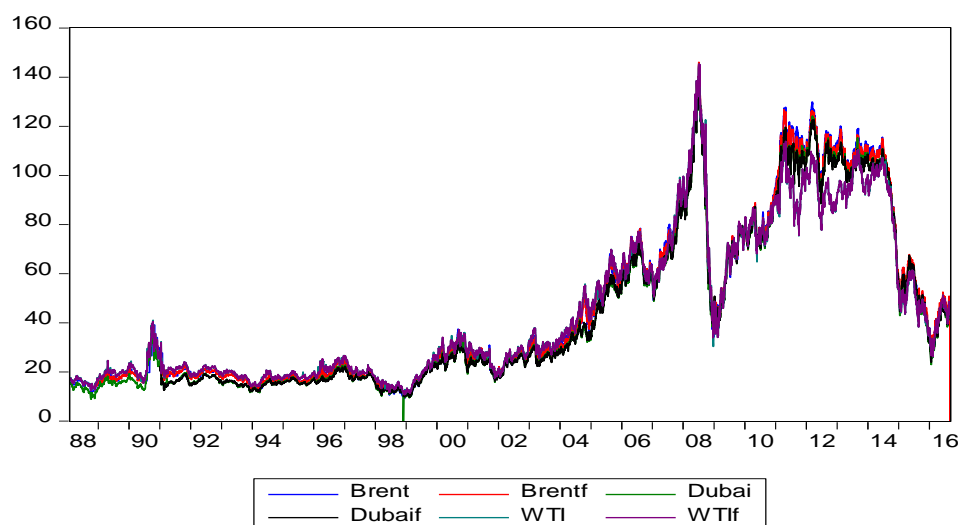
6.4 Data and Methodology

Spot and futures prices for three main crude oil benchmarks (Brent, WTI and Dubai) during times of crises are studied. The broad period (1986 to 2016) includes events such as the first and second Gulf war, OPEC production cuts, natural disasters, terrorist attacks, and economic and financial crises, which can show periods of oil price inefficiency due to investors' overreaction during times of major uncertainty. Understanding oil prices dynamics, interlinkages and efficiency behaviours is crucial since these issues impact economies, markets performance and financial assets. In recent years, it has been argued that futures prices might be influenced by speculation and hedging activities and therefore their behaviour might differ from spot prices. However, this only happens for certain time periods (mainly during times of stability). That is why this research is focused on both markets, spot and futures, as they are identified as being equally important for oil market participants.

6.4.1 Data

The time period starts on 29 January 1986, which is a common date for Brent, WTI and Dubai spot prices. The end of the tested period is set at the time of the analysis, which is 5 September 2016. The data set consists of daily closing spot and continuous futures prices for the Brent, WTI and Dubai crude oil markets. A daily frequency was chosen to allow capturing any sudden changes in prices behaviour and also to have a sufficient number of observations for all the proposed modelling, as the data will be subject to divisions and there was a need to ensure that all testing procedures will be functional. The data was obtained from Thomson Reuters Datastream and all prices are given in US Dollars per barrel. All three indexes are considered as the main crude oil benchmarks, and thus testing their efficiency could provide relevant outcomes in terms of their efficiency/inefficiency levels during times of instability. Figure 6.1 shows the historical development of spot and futures prices for Brent, WTI and Dubai crudes. Oil prices show a similar trend over time, which questions the potential existence of differences in efficiency between them over time.

Figure 6.1: Spot and Futures Prices of Brent, Dubai and WTI Crudes



Source: Thomson Reuters Datastream (2017)

Table 6.1 highlights some of the major events impacting oil markets over the selected period of study. It is remarkable that nearly every two years oil markets are affected by a shock. Table 6.2 displays time periods for individual moving windows as a result of the identified events outlined in Table 6.1.

Table 6.1: Issues Impacting Oil Markets

Some of the Major Issues Impacting Oil Returns from 1986 to 2016	
1986	Saudis abandon swing producer role
1990/91	First Gulf war
1997/98	Asian crisis
1998	OPEC cuts production
2001	9/11 Attacks
2003	Second Gulf war
2005	Low spare capacity
2007/8	Wall street speculation, the global financial crisis
2009	OPEC cuts production
2011	Supply disruptions
2014	Global oversupply and oil price collapse

Table 6.2: Tested Periods

10 Year Moving Windows		
Windows	Date	No. of Observations
Window 1	29/1/1986 to 10/4/1996	2,661
Window 2	11/4/1996 to 22/6/2006	2,661
Window 3	23/6/2006 to 5/9/2016	2,662

5 Year Moving Windows		
Windows	Date	No. of Observations
Window 1	29/1/1986 to 6/3/1991	1,331
Window 2	11/3/1991 to 11/4/1996	1,331
Window 3	12/4/1996 to 18/5/2001	1,331
Window 4	19/5/2001 to 26/6/2006	1,331
Window 5	27/6/2006 to 2/8/2011	1,331
Window 6	3/8/2011 to 5/9/2016	1,244

2 Year Moving Windows		
Windows	Date	No. of Observations
Window 1	29/1/1986 to 11/2/1988	532
Window 2	12/2/1988 to 26/2/1990	532
Window 3	27/2/1990 to 11/3/1992	532
Window 4	12/3/1992 to 25/3/1994	532
Window 5	28/3/1994 to 9/4/1996	532
Window 6	10/4/1996 to 23/4/1998	532
Window 7	24/4/1998 to 8/5/2000	532
Window 8	9/5/2000 to 22/5/2002	532
Window 9	23/5/2002 to 4/6/2004	532
Window 10	7/6/2004 to 20/6/2006	532
Window 11	21/6/2006 to 3/7/2008	532
Window 12	4/7/2008 to 19/7/2010	532
Window 13	20/7/2010 to 1/8/2012	532
Window 14	2/8/2012 to 15/8/2014	532
Window 15	18/8/2014 to 5/9/2016	536

In order to have robust outcomes, the research methodology is founded on the implementation of a variety of well-known Variance Ratio tests. The most established are the Variance Ratio (VR) tests (Lo and MacKinlay, 1988 and 1989; Chow and Denning, 1993), and the more recent wild bootstrap tests (Kim, 2006 and 2009). The use of multiple VR tests is justified by the research methodologies identified in the reviewed literature (Charles and Darné, 2009). The VR tests applied in this study are robust to heteroskedasticity and non-normality, which are features of crude oil prices (Wang and Wu, 2012; Salisu and Fasanya, 2013; Charles and Darné, 2014; Wang et al., 2016). To strengthen the analysis, Monte Carlo simulations using GARCH (1,1) as proposed by Charles et al. (2011) are also considered. Moreover, the theory and implications of adaptive market hypothesis under the behavioural finance stream are also adopted in order to critically examine the results. The sections that follow offer a brief discussion of each test used in this paper.

6.4.2 Variance Ratio Tests

The Variance Ratio (VR) test is widely used for efficiency testing (Liu and He, 1991; Hoque et al., 2007; Charles and Darné, 2009; Charles et al., 2011). Therefore, it was decided that this paper would begin with the implementation of the conventional Lo and MacKinlay (1998) VR test, to be followed by the Chow-Denning (1993) and Wright (2000) models. Afterwards, more recent techniques like wild bootstrapping by Kim (2006) are introduced and the final test to be considered is Monte Carlo simulation using GARCH (1,1) residuals as proposed by Charles et al. (2011).

6.4.2.1 Lo and MacKinlay (1988, 1989)

Lo and MacKinlay (1988, 1989) first introduced the VR test for efficiency testing. They proposed a test statistic under homoscedasticity and also under heteroskedasticity. As all our data shows evidence of heteroskedasticity, we perform the test under this assumption. Firstly, we specify our regression by P_t being the spot/futures price of crude oil daily prices at the time t and define $X_t = \ln P_t$ as the log price process. Given a time series $\{X_t\}_{t=1}^T$, the random walk hypothesis corresponds to $\theta = 1$ in the first order autoregressive model as:

$$X_t = \mu + \theta X_{t-1} + \varepsilon_t \quad (6.1)$$

where μ is the arbitrary drift parameter and ε_t is the random disturbance term. Since financial data exhibits changing volatilities over time, the specification test of random walk model must be robust to changing variances. If oil prices follow a random walk or martingale then the price return is unpredictable from the past price information. Following Wright (2000), the VR test can be written as:

$$VR(x; k) = \left\{ \frac{1}{Tk} \sum_{t=k}^T (x_t + x_{t-1} + \dots + x_{t-k+1} - k\hat{\mu})^2 \right\} \div \left\{ \frac{1}{T} \sum_{t=1}^T (x_t - \hat{\mu})^2 \right\} \quad (6.2)$$

where $\hat{\mu} = \frac{1}{T} \sum_{t=1}^T x_t$. This is an estimator for the unknown population VR, denoted as $V(k)$, which is the ratio of $1/k$ times the variance of the k -period return to the variance of the one-period return. Lo and MacKinlay (1988) showed that if x_t is independent and identically distributed (iid), then under the null hypothesis that $V(k) = 1$,

$$M_1(x; k) = (VR(x; k) - 1) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \quad (6.3)$$

follows the standard normal distribution asymptotically. To allow for x_t 's showing conditional heteroskedasticity, Lo and MacKinlay (1988) proposed a test statistic robust for heteroskedasticity,

$$M_2(x; k) = (VR(x; k) - 1) \left(\sum_{j=1}^{k-1} \left[\frac{2(2k-j)}{k} \right]^2 \delta_j \right)^{-1/2} \quad (6.4)$$

which follows the standard normal distribution asymptotically under null hypothesis that $V(k) = 1$, where,

$$\delta_j = \left\{ \sum_{t=j+1}^T (x_t - \hat{\mu})^2 (x_{t-j} - \hat{\mu})^2 \right\} \div \left\{ \left[\sum_{t=1}^T (x_t - \hat{\mu})^2 \right]^2 \right\} \quad (6.5)$$

This test is powerful when testing against mean reverting alternatives to RWH, especially when k is large.

6.4.2.2 Chow-Denning (1993)

In comparison to the Lo and MacKinlay (1988) test, which is an individual test where the null hypothesis is tested for an individual value of k , there is the question as to whether stock

returns are mean-reverting, which will require the null hypothesis to hold for all values of k . Therefore, it is necessary to conduct a joint test, where a multiple comparison of VRs over a set of different time horizons is made. Under the null hypothesis, $V(k_i) = 1$ for $i = 1, \dots, l$ against the alternative hypothesis that $V(k_i) \neq 1$ for some i . Their test statistic is as follows:

$$MV_1 = \sqrt{T} \max_{1 \leq i \leq l} |M_1(x; k_1)| \quad (6.6)$$

where $M_1(x; k)$ is defined in {3}. The idea is that the decision regarding the null hypothesis can be based on the maximum absolute value of the individual VR statistics. The null hypothesis is rejected at α level of significance if the MV_1 statistics is greater than the $\{1 - (\alpha^*/2)\}$ th percentile of the standard distribution, where $\alpha^* = 1 - (1 - \alpha)^{1/l}$. The heteroskedasticity-robust version of this test can be written as:

$$MV_2 = \sqrt{T} \max_{1 \leq i \leq l} |M_2(x; k_i)|, \quad (6.7)$$

which is a joint test using $M_2(x; k)$ as given in (6.4).

6.4.2.3 Wright (2000)

The standard VR test is based on asymptotic approximations, which may be biased and right-skewed in a finite sample and this can result in misleading inferences (Lo and MacKinlay, 1989). Wright (2000) proposes to modify the standard VR test using standardised ranks and signs. This approach has two advantages: firstly, as the sign and rank tests have exact sampling distribution, there is no need to resort to asymptotic approximation. Secondly, the tests may be more powerful than the conventional VR tests when the data is highly non-normal (Wright, 2000). The proposed statistics are as follows:

Let $r(x_t)$ be the rank of x_t among x_t 's and consider the standardised rank $r_{1t} = [r(x_t) - 0.5(T+1)]/[(T-1)(T+1)/12]$. Under the null hypothesis that x_t is generated from an iid sequence, $r(x_t)$ is a random permutation of the numbers of $1, \dots, T$ with equal probability.

$$R_1 = \left(\frac{(Tk)^{-1} \sum_{t=k}^T (r_{1t} + r_{1t-1} + \dots + r_{1t-k+1})^2}{T^{-1} \sum_{t=1}^T r_{1t}^2} \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \quad (6.8)$$

$$R_2 = \left(\frac{(Tk)^{-1} \sum_{t=k}^T (r_{2t} + r_{2t-1} + \dots + r_{2t-k+1})^2}{T^{-1} \sum_{t=1}^T r_{2t}^2} \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \quad (6.9)$$

6.4.2.4 Kim (2006)

Kim (2006) offers a wild bootstrap approach to improving the small sample properties of variance ratio tests with unknown forms of conditional and unconditional heteroskedasticity. The approach involves computing the individual Lo and MacKinlay $M_2(k)$ and joint Chow-Denning $MV_2(k_i)$ VR tests on samples of T observations formed by weighting the original data by mean 0 and variance 1 random variables. The results are used to form bootstrap distributions of the test statistics.

The wild bootstrap test based on $MV_2(k_i)$ can be computed in three stages as follows:

- 4) Form a bootstrap sample of T observations $X_t^* = \eta_t X_t (t = 1, \dots, T)$ where η_t is a random sequence with $E(\eta) = 0$ and $E(\eta^2) = 1$.
- 5) Calculate the $MV^* = MV_2(X^*; k_i)$ statistic obtained from the bootstrap sample generated in stage 1).
- 6) Repeat 1) and 2) sufficiently, say m , times to form a bootstrap distribution of the test statistic $\{MV_2(X^*; k_i; j)\}_{j=1}^m$.

The p -value of the test can be obtained as the proportion of $\{MV_2(X^*; k_i; j)\}_{j=1}^m$ greater than the sample value of $MV_2(k_i)$. The wild bootstrap version of $M_2(k)$ test can be implemented in a similar way as a two-tailed test, where we obtain $M^* = M_2(X^*; k)$ in stage 2) and $\{MV_2(X^*; k_i; j)\}_{j=1}^m$ in stage 3). Conditionally on X_t , X_t^* is a serially uncorrelated sequence with zero mean and variance X_t^2 . M^* and MV^* have the same asymptotic distributions as $M_2(k)$ and $MV_2(k_i)$ respectively. Since X_t^* is a serially uncorrelated sequence, wild bootstrapping approximates the sampling distributions under the null hypothesis, which is a necessary property for a bootstrap test. Kim (2006) recommends using the standard normal distribution as other choices provide similar results, and therefore we follow the same approach.

6.4.3 Monte Carlo Simulations

Charles et al. (2011) used Monte Carlo simulations to test for market efficiency. They considered a number of linear and non-linear models. We apply the linear models to stay consistent with the VR methodology, where we test the RWH against stationary alternatives by using the fact that the variance of random walk increments is linear in all sampling intervals.

The linear models are:

- AR(1) model: $Y_t = 0.1Y_{t-1} + Z_t$, and $Y_t = 0.1Y_{t-1} + V_t$
- ARFIMA model: $(1 - L)^{0.1}Y_t = Z_t$, and $(1 - L)^{0.1}Y_t = V_t$
- The sum of a white noise and the first difference of a stationary autoregressive process of order one (NDAR): $Y_t = \varepsilon_t + X_t - X_{t-1}$ with $X_t = 0.85X_{t-1} + \mu_t$

where $Z_t = \varepsilon_t\mu_t$ with $\sigma_t^2 = 0.001 + 0.90\sigma_{t-1}^2 + 0.09\varepsilon_{t-1}^2$ (i.e. GARCH(1,1) errors);

$V_t = \exp(0.5h_t) \varepsilon_t$ with $h_t = 0.95h_{t-1} + \mu_t$ (i.e. stochastic volatility (SV) errors); ε_t and μ_t are independent i.i.d $N(0,1)$. The number of bootstrap replications is 1,000.

6.4.4 Adaptive Market Hypothesis by Lo (2004)

The Adaptive Market Hypothesis (AMH) by Andrew Lo (2004) was introduced as part of the behavioural finance stream, which argues that markets are not rational. The AMH implies that the degree of market efficiency is partially related to environmental factors, the number of competitors, profit opportunities and the adaptability of the market participants (Lo, 2004). It claimed that behavioural biases occur quite often in financial markets, such as overreaction, overconfidence or loss aversion, and these can be based on changing environments. Lo (2004) also argues that hedge funds, pension funds, market makers and other market participants are considered as a distinct group, which has an impact on market efficiency. More specifically, if more species²⁰ are competing within a single market, efficiency tends to be high. On the other hand, if a small number of species are challenging a more rare market, efficiency is low. Therefore, under the AMH, investment strategies undergo cycles of profitability and loss in response to changing business conditions, the number of competitors entering and exiting the industry, and the type and magnitude of profit opportunities. This theory has several implications, outlined as follows: i) The relationship between risk and reward exists, but it is unlikely to be stable over time. ii) Arbitrage opportunities do exist from time to time. iii) Investment strategies will perform well in certain environments and poorly in other environments. iv) Innovation is the key to survival. v) Survival is the only objective that matters.

²⁰ By species, is meant distinct groups of market participants, each behaving in a common manner. For example, pension funds may be considered one species; retail investors, another; market makers, a third; and hedge-fund managers, a fourth.

However, this theory is difficult to test or examine based on the irrationality behind people's decisions; consequently, this paper considers the theoretical implications behind this theory to help explain some of the research outcomes and keep the econometric testing in the context of the EMH. To summarise the proposed research methodologies, Table 6.3 displays the main methodological advantages of the chosen models. The combination of selected methods helps offer an extended efficiency analysis to those outcomes available in the existing literature and to bring a richer research framework to this study.

Table 6.3: Methodologies

Applied Methodologies	Main advantages
Lo and MacKinlay (19988 and 1989)	Widely used original variance ratio test. This test is considered to be robust under the existence of heteroskedasticity
Chow and Denning (1993)	Multiple VR test, its main advantage if that allows for multiple comparisons
Wright (2000)	Exact VR test using ranks and signs that help minimise size distortions
Kim (2006)	Wild bootstrap test, which is a resampling method that approximates the sampling distribution of a test statistics
Charles et al. (2011)	Monte Carlo simulations using GARCH (1,1) residuals applied to the wild bootstrap approach, which is applicable to data with unknown conditional and unconditional heteroskedasticity
Lo (2004)	AMH offers explanations for and the implications of investors decisions, which might not be explained by econometric models

The proposed models include popular methodologies used for efficiency testing. The VR methodology used by Lo and MacKinlay (1988 and 1989) consists of testing the RWH against stationary alternatives because the variance or random walk increments are linear in

all sampling intervals. It is a simple approach, but it typically uses overlapping data in computing the variance of long horizon returns, which could lead to difficulties in analysing the exact distribution of the VR statistics. Following this fact, Chow and Denning (1993) proposed the multiple comparison tests. Both methods are powerful under homoscedasticity and heteroskedasticity, but their sampling distributions are approximated by their limiting distributions showing severe bias and right skewness. Therefore, the Wright (2000) test offers the exact VR test based on ranks and signs, and Kim (2006) proposes the wild bootstrap test, which is a resampling method that approximates the sampling distribution of the VR statistics. It is applicable to data with unknown forms of conditional and unconditional heteroskedasticity. This also applies to Monte Carlo simulations proposed by Charles et al. (2011), which use the residuals of the GARCH (1,1) model for the estimations. Lastly, the AMH by Lo (2004) enhances the analysis by including the behavioural aspect behind investors' actions, especially during shock periods.

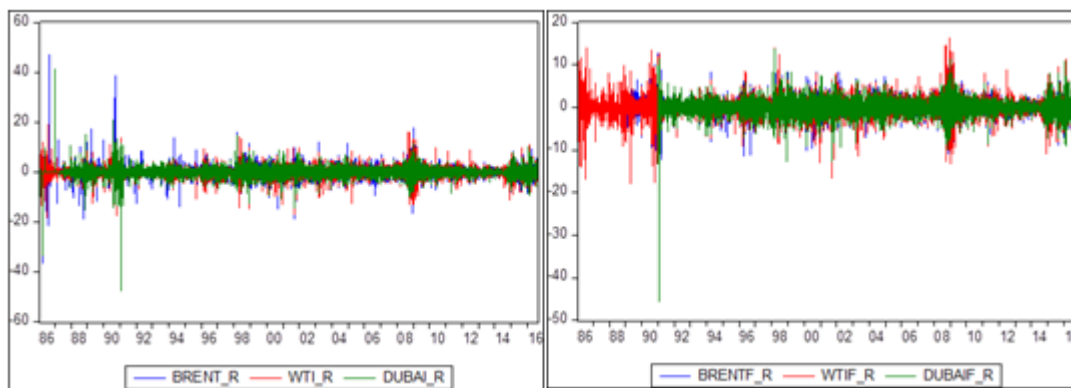
6.5 Empirical Findings

Before applying the chosen research models, the data is tested for stationarity, to ensure that standard tests on time series analysis are properly estimated and analysed. The results indicate that the data is non-stationary in levels (prices), but stationary in returns. This is consistent with all existing literature studying crude oil markets. The returns of spot and futures prices were calculated as the natural log returns, where $return_t = \ln\left(\frac{price_t}{price_{t-1}}\right)$. Afterwards, the return series are tested for evidence of heteroskedasticity and non-normality, finding that spot and futures returns are non-normal with the presence of heteroskedasticity²¹ (Narayan and Narayan, 2007; Maslyuk and Smyth, 2008). This is a common feature of

²¹ These results are not included in this paper for the sake of brevity, but are available upon request.

financial data series, and according to the reviewed literature there is a need to ensure that all basic testing is performed before the econometric testing moves forward. Figure 6.2 displays the returns for spot and futures prices and in Appendix A a summary of the statistics of the analysed data are reported.

Figure 6.2: Brent, WTI and DUBAI Spot and Futures Price Returns



Source: Thomson Reuters Datastream (2017)

In Figure 6.2 above, it is possible to appreciate a clear increase in returns fluctuation during 1986, 1988, 1991, 1998, 2001, 2008 and from 2014 onwards. This can be linked to the events in Table 6.1, where core periods of market instability in oil prices and returns were highlighted. Table 6.5 in Appendix A presents the summary statistics for spot and futures prices in levels and returns for the whole period from 1986 to 2016²². All three crude benchmarks have approximately the same mean returns of about 0.01 percent a day, with Brent spot returns marginally smaller than WTI and Dubai, but with Brent futures returns being slightly higher than WTI and Dubai. This is most likely due to the fact that Brent futures are the most traded by volume. The standard deviation, which is a measure of risk, is between 2.1 percent and 2.4 percent. All returns are non-normal, showing significant negative

²² Summary statistics for each moving window are available upon request.

skewness (except for Brent spot returns that are above zero) and excess kurtosis. However, the outcomes are considerably different for those sub-periods in which shocks affected oil prices. For example, during the first Gulf War in 1990/91 the mean returns for Brent spot and futures are found to be negative at 0.02 percent a day and the standard deviation was above 3 percent. Similar results are found for the WTI and the Dubai spot and future prices. When the results are compared to the outcomes for the 1994 to 1996 time period, the results show that mean returns are positive and above 0.7 percent a day and standard deviation is around 1.5 percent a day. These significant variances may have an impact on efficiency testing and confirm that unstable periods are associated with different patterns and dynamics. Table 6.4 highlights the main tests' outcomes. In order to offer a clear picture of the main research outcomes a summary table was developed, as it facilitates the understanding of the main results for each of the implemented econometric models and moving windows.

Table 6.4: Results Summary

			Applied Methodologies				
			Lo-MacKinlay	Chow-Denning	Wright	Kim	Monte Carlo
10 yr window	1986 to 1996	"Brent, WTI, Dubai	X	X	X	X	X
	1996 to 2006	"Brent, WTI, Dubai	X	X	X	X	X
	2006 to 2016	"Brent, WTI, Dubai	X	X	X	X	X
5 yr window	1986 to 1991	*Dubai futures	✓	✓	✓	✓	✓
	1991 to 1996	"Brent, WTI, Dubai	X	X	X	X	X
	1996 to 2001	"Brent, WTI, Dubai	X	X	X	X	X
	2001 to 2006	"Brent, WTI, Dubai	X	X	X	X	X
	2006 to 2011	"Brent, WTI, Dubai	X	X	X	X	X
	2011 to 2016	"Brent, WTI, Dubai	X	X	X	X	X
2 yr window	1986 to 1988	Dubai spot	✓	X	X	✓	✓
	1988 to 1990	"Brent, WTI, Dubai	X	X	X	X	X
	1990 to 1992	*Dubai futures	✓	X	X	✓	✓
	1992 to 1994	"Brent, WTI, Dubai	X	X	X	X	X
	1994 to 1996	WTI spot and future:	X	X	✓	X	X
	1996 to 1998	"Brent, WTI, Dubai	X	X	✓	X	X
	1998 to 2000	"Brent, WTI, Dubai	X	X	✓	X	X
	2000 to 2002	"Brent, WTI, Dubai	X	X	✓	X	X
	2002 to 2004	"Brent, WTI, Dubai	X	X	✓	X	X
	2004 to 2006	"Brent, WTI, Dubai	X	X	✓	X	X
	2006 to 2008	"Brent, WTI, Dubai	X	X	✓	X	X
	2008 to 2010	"Brent, WTI, Dubai	X	X	✓	X	X
	2010 to 2012	"Brent, WTI, Dubai	X	X	✓	X	X
	2012 to 2014	"Brent, WTI, Dubai	X	X	✓	X	X
	2014 to 2016	"Brent, WTI, Dubai	X	X	✓	X	X

*results are influenced by the fact that Dubai futures dataset starts from 2/1/1991 making the time period shorter
✓ means RWH confirmed, and X means RWH rejected. " means results apply for spot and futures.

Source: The author (2018)

Before discussing the outcomes we note that the original VR test by Lo-MacKinlay exhibits similar outcomes to more recent models of bootstrapping and Monte Carlo simulation. However, the Chow-Denning and Wright tests display different outcomes. This suggests that the selection of the methodology, the data set and the length of the moving windows play a major role in the final outcomes.

The main research findings are summarised as follows: The Variance Ratio tests and Monte Carlo simulations using GARCH (1,1) residuals, which are robust to heteroskedasticity and non-normality, show that for the 10 year moving window all markets are found to be

inefficient. This may be accounted for by structural breaks in the series arising from economic and financial crises, wars and OPEC's decisions impacting the oil returns by high volatility. Therefore, the outcomes might be affected by multiple shocks in the series as the time period is quite long, which may create estimation issues. This is consistent with Lim et al. (2008) and Lo (2004) and his AMH findings, where they suggest that chaotic times may lead to higher uncertainty and market overreaction. This is however, in contrast with Fama's EMH (1965 and 1970) where he believes in market efficiency and does not include any behavioural component in his theory. In the case of the 5 year moving window, the results show that the Dubai futures market is efficient between 1986 and 1991. This is confirmed by all the efficiency tests applied. However, the data set for Dubai futures starts in January 1991, meaning that we have data for only one year in this moving window and we could look at it as a short horizon analysis, which is consistent with Robert Shiller and his theory that stock prices can be predicted over a long time period, but not in the short run. The 2 year moving window results are quite different. The Lo and MacKinlay (1988 and 1989) and Kim's (2006) wild bootstrap and Monte Carlo simulation using GARCH (1,1) residuals (Charles and Darné, 2011) indicate that the Dubai spot market is efficient between 1986 and 1988. The same tests confirm that the Dubai futures market is efficient between 1990 and 1992. Wright's test identified WTI spot and futures markets to be efficient between 1994 and 1996 at 30 lags. Wright's tests also showed all markets being efficient between 1996 and 2014 at 30 lags. Between 2014 and 2016 all markets were found to be efficient at 30 lags and the Dubai futures market also at 10 lags. This is in contrast with Charles and Darné (2009) who suggested that the Brent spot market is weak form efficient from 1982 to 2008 and the WTI spot market is inefficient for the period 1994 to 2008. The differences in results could be explained by the selection of different time periods and the implementation of moving windows with different lengths.

The results, indicating potential inefficiency for the 10 year moving window, suggest that market returns can be predicted in the long run. This is consistent with the findings of Wang and Wu (2013), where the authors reported findings that align with these research paper outcomes in the context of oil futures prices. On the other hand, Gu et al. (2013) believe that market inefficiencies are more evident in the short run. If we look at the dynamics and characteristics of oil markets and consider high and frequent oil price jumps due to shocks in the market, it could highly influence the tests' outcomes and provide spurious results (Khediri and Charfeddine, 2015). Thus, the window size selection (in this case 2, 5 and 10 year sizes) offers the analysis outcomes in short, medium and long term views, which should control for jumps in the tested time series, where periods of high uncertainty are carefully analysed under the consideration of each one of the selected benchmarks.

The implications of the above outcomes suggest that in the short term horizon the EMH holds and that it is hard to predict oil prices. On the other hand, investors have higher chances of beating the market in the long run if they know the changing patterns influenced by the exogenous causes, such as supply and demand levels based on production quotas and economic growth, the global economic and financial situation and political activities.

6.6 Conclusions

This paper investigates the weak form of market efficiency of three crude oil benchmarks: Brent, WTI and Dubai from 1986 to 2016. Spot and futures prices were included in our analysis using the 2, 5 and 10 year moving window approach. Various variance ratio tests, wild bootstrapping, Monte Carlo simulations and the adaptive market hypothesis were considered in a combined approach to enrich the discussion. The main focus of this study was

to analyse oil prices efficiency highlighting periods of crises and uncertainty, which could potentially distort the tests' outcomes. The 10 year moving window approach showed that all markets were found to be inefficient. This can be explained by high oil price volatility affected by economic and financial crises, wars and OPEC's decisions impacting the efficiency outcomes that created changes of patterns on the series and that could end up affecting the estimations. The analysis for the 5 year moving windows shows that the Dubai futures market is efficient between 1986 and 1991. However, the data set for Dubai futures starts from 2 January 1991, which considerably shrinks the time period, which could be the main reason for this result. The 2 year moving window results are quite mixed. The Dubai spot market is found to be efficient between 1986 and 1988, while the Dubai futures market between 1990 and 1992, and the WTI spot and futures markets are efficient between 1994 and 1996. The tests also showed that all markets are efficient between 1996 and 2016. This suggests that shorter time periods might not be affected by so many shocks, and that oil prices might be moving in a random fashion making it quite difficult to make predictions and to benefit from the existence of market inefficiencies.

The main contributions of this paper can be summarised in three central additions to the existent literature. Firstly, we are using multiple, simple, and joint VR tests to analyse if oil markets are efficient, as a comparative analysis also allows for cross checking results. We found that the Lo-MacKinlay test, Kim's bootstrap and Monte Carlo simulation offered consistent results, compared to Chow-Denning and Wright's findings. These inconsistencies might be due to high oil price fluctuations affecting the outcomes. Secondly, all chosen models are applied on the world's major oil prices benchmarks - Brent, WTI and Dubai crude oil spot and futures prices - simultaneously to offer valuable information to oil market investors, speculators and hedgers in terms of oil price predictability and portfolio

management. Thirdly, the analysis was supported by the implementation of a three fixed moving windows approach (10, 5 and 2 years) to help examine the outcomes for different time periods with a specific focus on crises periods, finding that the implications of the adaptive market hypothesis are evident in the oil markets. Future research studies in the field should look closer at the analysis of the underlying factors affecting oil markets inefficiencies under the adaptive market hypothesis that will help provide a better understanding of oil prices behaviour.

Appendix

Table 6.5 Summary Statistics

	Daily Prices						Daily Returns					
	Brent	Brent Futures	WTI	WTI Futures	Dubai	Dubai Futures	Brent	Brent Futures	WTI	WTI Futures	Dubai	Dubai Futures
No. Observations	7,984	7,239	7,984	7,983	7,984	6,698	7,984	7,236	7,984	7,983	7,980	6,697
Mean	43.697	46.6889	42.8837	42.8951	41.284	46.14662	0.007184	0.016904	0.01034	0.009895	0.011491	0.009724
Median	26.465	29.05	27.89	27.85	24.46	28.83	0	0	0	0	0	0
Max	143.6	146.08	145.31	145.29	141.08	141.23	47.1346	13.15063	19.2371	16.40973	41.27168	13.76713
Min	9.14	0	10.25	10.42	0	9.77	-36.4403	-42.72233	-40.6861	-40.04776	-47.74678	-45.57063
Std. Dev.	34.007	34.333	30.3348	30.3743	33.1677	33.9677	2.38051	2.21653	2.4993	2.44107	2.26947	2.060639
Skewness	1.06086	0.9075	0.9775	0.9745	1.0615	0.8096	0.4816	-1.13724	-0.6783	-0.73502	-0.83617	-1.68656
Kurtosis	2.75833	2.44692	2.6662	2.658324	2.74282	2.2507	58.9927	25.68843	17.28454	17.1963	51.78803	41.1672
Jarque-Bera	1,516.99	1,086.03	1,308.56	1,302.36	1,521.43	888.4637	1,043,283.00	156,761.30	68,492.22	67,754.35	792,370.20	409,664.70
Prob.	0	0	0	0	0	0	0	0	0	0	0	0
Time Period	29/1/1986 to 5/9/2016											
Data Source	Datastream and Eviews											

Chapter 7

Conclusions

7.1 Introduction

This chapter summarises the main research findings of this thesis, which are outlined in the three research papers (themes) in the study. It presents the outcomes for lead-lag dynamics of crude oil spot and futures prices by analysing the long and short run relationship, volatility and efficiency between both prices with especial attention to periods of significant market uncertainty that are identified by major crises periods over the past few decades. The chapter then outlines the key motivation and objectives of the study, its main findings and their implications. It also discusses the limitations of the study and ideas for related further research.

The highlights of this thesis' outcomes point out to the existence of a bi-directional long run relationship between crude oil spot and futures prices. On the other hand, the short run lead-lag relationship between oil prices show mixed indications, where the relationship changes depending on the selected time period. More specifically, futures prices seem to lead during relatively stable periods and spot prices during times of distress, which is a very important input in the decision-making processes of investors, and oil market players. Similarly, the outcomes of the volatility analysis offer important insight for investment strategies as the evidence puts forward clear differences in oil prices volatility between the different types of crises, where direct supply/demand shocks lead to higher volatility spikes and economic/financial shocks have longer volatility persistence. Furthermore, the research

outcomes for the efficiency side of the analysis also show conflicting evidence with regard to market efficiency patterns between spot and future prices as the results change depending on the selected econometric model.

7.2 Research Main Motivation and Objectives

The thesis main research motivation and objectives come from the importance of crude oil as the world's main energy resource. The lead-lag relationship and dynamics between spot and futures prices play an important role in understanding their behaviour during times of major distress, as it affects industries and economies dependent on oil. As shocks in the oil markets are a common feature, it is quite likely that they will happen again and therefore it is vital to recognise and understand oil prices relationships during such times. This could help minimise the levels of uncertainty and risks associated with oil prices fluctuations. Therefore, the key focus of this thesis is to contribute to the understanding of crude oil prices behaviour during selected economic and financial crises, and to highlight patterns and similarities during turbulent times which could help predict oil prices lead-lag dynamics. The thesis is structured around three major issues which aim to identify spot and future prices relationships.

1. Firstly, the lead-lag relationship in the long and short run is tested between oil spot and futures prices.
2. Secondly, volatility analyses during major crises are examined.
3. Thirdly, the efficiency of oil prices is tested under the Efficient Market Hypothesis.

The research questions were formed to help understand crude oil behaviour and dynamics during crises periods and the reviewed literature offered a solid base for appropriate methodology selection.

7.2.1 Research Questions

The main research questions start with the lead-lag analysis of crude oil spot and futures prices long run and short run relationships, where the behaviour of the two prices is examined. The study's main focus examines how oil prices dynamics were affected during times of significant levels of uncertainty. The main purpose is to understand if prices experience significant variations with regard to their lead-lag relationship during crises and stable periods. Hence, the first main research question is:

Q1. Is there long and short run (cointegration and causality) relationships between crude oil spot and futures prices? This is considered a very important issue for the decision making process, as the leading price could offer insights on oil market price movements. This is tested in Paper 1 of Chapter 4.

Secondly, as the crises periods impact on oil prices levels, the volatility of oil prices is considered a very important indicator of oil price changes, and therefore volatility is examined for two different crises (the first Gulf War and the global financial crisis). The second research question is as follows:

Q2. Is volatility of crude oil spot and futures prices higher during periods of crises? The main goal of examining the volatility of oil prices is to identify the impact of crises triggers

on crude oil spot and futures prices, which could predict differences in volatility outcomes during various shock periods. Detailed outcomes are presented in Paper 2 of Chapter 5.

Thirdly, an important part of oil prices examination is to test its efficiency under the random walk hypothesis to see if oil prices can or cannot be predicted by past price movements. The third research question is therefore constructed as:

Q3. Are crude oil spot and futures prices efficient in the long, medium and short run?

For that reason, efficiency is tested for multi-period time frames to integrate the findings for investment and strategic planning in paper 3 of Chapter 6.

The three research questions are relevant for crude oil markets behaviour examination and add value to the literature in this field by offering comparative analysis of the relationship and dynamics of crude oil prices during different crises. As a result, the findings of this thesis are both interesting and have significant implications.

7.3 Research Findings

The key research findings are divided into three main themes: 1) the long and short run relationship, 2) volatility findings, and 3) efficiency outcomes, where the existing literature offered a base for the analysis.

The long run relationship results between crude oil spot and futures prices show that the two prices for Brent crude oil markets are cointegrated, which is consistent with studies such as Mamatzakis and Remoundos (2011) and Zhang and Wang (2013). This means that there is not a distinct leading price which should be followed while making investment

decisions. The outcomes for short run relationships suggest that at some points in time during crises periods, the spot price seems to lead the futures price, and in the relatively stable periods before and after the crises, futures prices appear to be leading the spot prices. This suggests the existence of dynamic oil price linkages.

The volatility analysis points out differences in volatility spikes and persistence during economic/financial crises and supply/demand disruption shocks. The testing outcomes show that volatility spikes are much higher during supply/demand shocks (such as the first Gulf War in 1990/91 or the US terrorist attack in 2001), but does not last as long as the economic/financial shocks (the Asian financial crisis in 1997/98 or the global financial crisis in 2008/09) that exhibited lower volatility spikes and higher persistence. Salisu and Fasanya (2013) also pointed out in their study that negative news, such as crises or shocks in the market, affect oil prices more than positive news in the oil market.

The efficiency results for long, medium and short term periods under the EMH using numerous econometric tests and moving windows approaches shows mixed outcomes. The Random Walk hypothesis is not confirmed in all instances by the econometric models. Some of the tests indicate that oil prices are efficient for some time periods; however, this is not supported by all tested methods. This is in contrast to the findings of Lean et al. (2010), Khediri and Charfedinne (2015) and Gu and Zhang (2016) who found oil markets to be efficient. Potential differences in crude oil markets efficiency outcomes could be affected by chosen time periods and different time window lengths.

The results reveal a pattern of lead-lag relationships between crude oil spot and futures prices, which indicates the difference for long or short term investment decision making as

in the long run, there is not a leading price for Brent markets; however, for short run strategies the futures market seem to dominate the spot market during relatively stable periods, but the spot market is the oil price indicator during crises periods. The lead-lag relationship is also supported by the volatility outcomes, where the patterns of volatility spikes and persistency help with strategic planning by reducing risk through short or long term hedging tactics. The efficiency analysis indicates that in times of market inefficiencies, there could be potential space for increased speculation in the oil markets.

The implications of the research outcomes indicate that the prediction of oil markets dynamics depends on many factors, such as time frequency and chosen time periods, where the crises periods appeared to affect oil markets in a significant manner. This has an impact on oil markets' fluctuating behaviour and oil price risk, which can be reduced by suitable hedging approaches based on given information.

7.4 Contributions to Existing Research

The main contributions of this thesis are as follows:

After the existent literature review, significant research gaps were found, which if filled could add to the existent knowledge. More specifically, the addition of research findings paying particular attention to major crises was needed to understand crude oil prices during highly turbulent and uncertain times. The existing studies , Zhang and Wang 2013; Charles and Darné (2014); Robe and Wallen 2015; Loutia et al. 2016; Wang et al. 2016) analyse the behaviour of crude oil prices looking at cointegration (Bekiros and Diks, 2008; Mamatzakis and Remoundos, 2011), causality (Bekiros and Diks, 2008; Ding et al., 2014), volatility (Sadorsky, 2006; Salisu and Fasanya, 2013; Wang et al., 2016) and efficiency

(Hoque et al., 2007; Charles and Darné, 2011, Hamilton, 2013, Loutia et al., 2016), where crises periods occur, but detailed analysis of crude oil behaviour during major shocks is vital to help understand oil price levels during highly uncertain times. Therefore, this thesis examines and compares different crises and stable periods with the help of numerous structural break tests. This highlights the main differences of oil prices behaviour which identifies certain patterns depending on the triggers of periods of instability. The main distinction is paid to the evaluation of the behaviour causing supply/demand shocks compared to economic/financial crises. While a clear case is made for the existence of a short term relationship, the significant value of this research is that it shows that futures prices tend to lead during stable periods compared to times of crises where spot prices play the dominant role. Significant value is added by the volatility examination of crude oil markets during crises, where a specific pattern was found for different types of crisis. The efficiency analysis of spot and futures oil prices provides varied outcomes that highlight the need for this type of research due to the excessive variability of oil markets. The findings of this study benefit mainly policy-makers, oil dependent economies, industries and oil market investors through the added knowledge of oil prices performance during various crises.

Secondly, the choice of selected research methodologies offers a comparative analysis of the outcomes, which helped with explaining the results of such unsettled time periods. As it can be difficult to model time series data during highly turbulent periods, multiple models for each line of analysis were applied. Specific attention is paid to structural break analysis that helps to split the tested periods into crises and stable times, and to avoid distorted outcomes. The main research methods applied in this thesis comprise the Bai-Perron structural break test, Johansen cointegration test, Engle-Granger cointegration test, Granger

causality test, VECM model, GARCH (1,1) and Variance Ratio tests. The combined research methodologies lead to a rich econometric framework that has not to date been considered as a part of a research study. Together with the three different themes, this thesis offers an in-depth analysis that is significant to practitioners, academics and policy-makers by adding value through the extensive analysis of major crises which affected oil markets.

Thirdly, the lead-lag relationship analysis between crude oil spot and futures prices for various tests shows a clear research gap in connection with the volatility and efficiency literature. The reviewed literature discusses the lead-lag relationship applying cointegration and causality tests (Bekiros and Diks, 2008; Zhang and Wang, 2013), which offer findings on long and short run relationships. This thesis brings a greater level of understanding of the lead-lag relationship to volatility and efficiency analysis, where the different developments between crude oil spot and futures prices indicate the prices, which are more influenced by specific shocks. To the best of the author's knowledge, this was not previously done.

As a whole, this thesis puts forward three research papers, which in detail offer an analysis of crude oil markets dynamics with attention to a lead-lag relationship as this can help identify the leading oil price during times of distress. It will assist oil market players by integrating the findings of the thesis into their decision making processes. Table 7.1 highlights the main contributions of each research paper, some of the key literature and the value added to existing research.

Table 7.1: Core Contributions under Three Research Themes

	Paper 1	Paper 2	Paper 3
Key Contributions	1) Establishment of bi-directional long term relationships between Brent spot and futures prices during crises periods, and pre-crisis and post-crisis periods 2) Significant results for short term relationships between spot and futures prices, where futures prices tend to lead the spot prices during relatively stable periods, but spot prices tend to lead during crises periods	1) Volatility analysis outcomes identified significant differences between the crises triggers and effects on volatility spikes and persistence 2) The volatility persistence exhibited longer duration for economic/financial triggers than in cases of supply disturbances	1) Efficiency analysis of three main crude oil benchmarks during four major crises 2) Application of numerous econometric models for spot and futures oil markets during long term, medium term, and short term periods 3) Controversies over the efficiency outcomes for different models
Core Research Articles	Bekiros and Diks (2008), Zhang and Wang (2013), Ding et al. (2014), Kim (2015)	Sadorsky (2006), Salisu and Fasanya (2013), Charles and Darné (2014), Robe and Wallen (2015), Wang et al. (2016)	Hoque et al. (2007), Charles and Darné (2009), Charles and Darné (2011), Hamilton (2013), Loutia et al. (2016)
Value Added to Core Research Articles	Specific attention to different crises and stable periods, which highlight the details of crude oil spot and futures prices relationship	The triggers of different crises on volatility bring key value information for investment and decision-making processes	The efficiency outcomes confirm the random walk hypothesis for certain short time periods in contrast to long term periods, where efficiency was not established

Source: The author (2018)

The impact of higher oil prices during crises periods for oil importing countries can be enormous and affect the countries' economic growth. Therefore, it is important to include the analysis for crude oil spot and futures prices lead-lag relationships to improve monetary and fiscal policies so as to reduce oil price shocks during crises periods by understanding their behaviour. The integration of this thesis' findings should minimise the negative effect of high oil price changes during major crises. Furthermore, as mentioned throughout this thesis the outcomes can be integrated into government policies for oil importing countries concerning high oil price jumps that could prevent a downturn in countries performances and economic growth due to their high dependence on crude oil.

Time horizons play a vital role in planning and decision-making processes in crude oil markets, mainly through investment and hedging strategies. This is one of the key focuses of this thesis' analysis including long, medium and short term periods, which contributes to a deeper understanding of crude oil prices changing patterns. It helps to evaluate and manage the oil market risk, where the different investment concepts and rules must be considered with caution so as to determine the correct investment positions. In general, long term plans are not considered to be too sensitive to greater short-lasting volatility due to the long term investment horizon. On the other hand, short term investments must be carefully monitored to avoid significant risk concerning high oil price changes. Therefore, the analysis in this study of multiple long term, medium term and short term time periods adds considerable value to the existing crude oil literature by expanding the knowledge of crude oil markets behaviour.

7.5 Main Limitations of the Research

The results described above have to be treated with caution as some limitations may apply. Although the data and econometric models were chosen based on the crude oil literature to answer the research questions, the econometric models may be sensitive to significant jumps in the series as we are looking at times with shocks and high degrees of uncertainty. This could affect the outcomes, even though the robustness checks and structural break analysis have been applied to eliminate incorrect or spurious results.

The limitations also lie in the selected frequency of the data. Daily prices were used in this thesis, but they could be substituted with other frequencies like, for example, weekly or monthly data, which could lead to different results on oil prices dynamics. However, the selection of daily data was carefully chosen based on the appropriateness of this analysis and the applied econometric models. Moreover, the quantitative research framework of this thesis might not provide all the explanations for all possible outcomes. There could be other aspects to oil prices lead-lag relationships during crises periods, but the main research findings of the applied econometric models offer very clear indications of oil prices dynamics during major shocks. This is mainly, the importance of oil futures on oil spot markets and the triggers of crises on oil prices behaviour.

7.6 Further Research

The behaviour of crude oil markets is affected by high numbers of triggers. These could be economic, financial, investment, speculative and other triggers. Economic and financial theories are progressing and changing depending on the global economic situation and

therefore further research facilitates bringing other theories and techniques, such as behavioural finance theories, into crude oil market analysis. This could increase understanding of the rationale behind oil prices behaviour and investors decisions, especially during crises periods. A further study could focus on the irrationality and emotions behind investment decisions made in the oil markets through the behavioural finance stream, which could offer additional explanations for, and the implications of, investors' choices which are difficult to explain by econometric models. Also, an implementation of different research approaches could bring macroeconomic insights to oil markets analysis, such as the Data Envelopment Analysis (DEA) used for efficiency examination of oil demand for various oil dependent countries applied by Gómez-Calvet et al. (2014) and Narbón-Perpiñá et al. (2018). This could help understand the high frequency of oil price jumps and offer new insights for oil market participants. The expansion of analysis of lead-lag relationships of spot and futures prices between different crude oil benchmarks during additional shocks in the market would also be valuable to check geographical differences. This would offer detailed trading and investment strategies within crude oil markets and highlight possible hedging strategies against oil price risk.

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